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POETRY AND MUSIC; MUSICAL INTERPRETATION; AND SOME REMARKS ABOUT AMERICAN ORCHESTRAS

By Serge Koussevitzky

Received May 2, 1938 Presented April 13, 1938

Of all the arts, music and poetry are pre-eminently those that may be brought into closest union with one another. Such a connection is surely well founded, for, at the beginning, poetry and music formed a united and indivisible whole. In remote times they existed in a united and indivisible tonal art, and their separation took place rather late. One cannot, on a sound basis, consider painting as the mother of poetry, or affirm that literature gave birth to architecture. To admit that, would seem—if not an obvious absurdity—in any case, a great paradox. But, if we make a parallel between poetry and music, the situation changes. Between these two arts there is an extraordinary relationship and an astonishing nearness. One may follow the rise of poetry out of music or consider the inverse: the birth of music from poetry. Both modern philology and modern musical research agree that once poetry and music formed one art and dwelt in the midst of one united element.

The disjunction of poetry and music happened a long time ago, and each of these arts led its own existence and developed independently of the other; but their passionate attraction remained forever. Poetry always longs to be united to music, so that it tries from time to time to become music. This was the case with the symbolist poets ("De la musique avant toute chose" —Verlaine).

It is easy to bring together music and poetry. Both have one aim, if we recall the poet's words:

> "Go on and hasten
> To fill again my hungry soul
> With music."
> —Pushkin, "Mozart and Salieri"

However, we do not intend to make a parallel between the two arts in order to talk about their common features, but in order to distinguish one fundamental peculiarity which divides them: poetry is silent music. Its meaning is in the unexpressed and untold. Music is the singing voice of poetry.

This is the real reciprocal relation between poetry and music. When they are incorporated in concrete works, their relation becomes inverse. As much as they attract each other before their incarnation into form and images, so much do they repulse each other when taking a literary or tonal shape. This erotic union and disjunction is like a symbol, eternally repeating itself and calling to remembrance the bygone existing unity and the rapture which once occurred.

When poetry incorporates itself into verses, it needs tranquillity: it seems to be ashamed of its literary nudity and demands silence. On the contrary, music, when taking a concrete shape, appears to be chained by quietness and violently claims to be expressed in real tones. Only bad verses aspire to be pronounced, playing with the sonority of words; good verses are fond of stillness and silence. In music, we observe the opposite phenomenon; only bad music is hostile to its tonal expression—that is, music which contents itself with its outlines ('Papiermusik'). Good music requires to be unchained in reproduction. Recited poetry nearly always sounds rhetorical. Good verses must be read to oneself.

Music which does not sound appears to be a dead world and loses its significance; its meaning dwells only in the tonal realization. Verses which are not even read (let alone not pronounced) do not lose their active power, but keep, in a mysterious manner, the ascendency of poetry. Goethe and Petrarch do not lose their power and strength, but are independent of the fact whether they are remembered and read.

Music gave birth to the art of interpretation, creating in its own sphere a second and auxiliary art, which poetry does not know at all. In poetry, interpretation is very artificial and changes into a dramatic pose—a pose because it appears an imitation of theatrical art, from which poetical interpretation must borrow, for, in poetry's own sphere, as an organic art, it cannot arise. As an auxiliary art, interpretation is, above all, most closely connected with music.

The realm of interpretation in music, and especially the realm of conducting, is still very young, when we think that Berlioz, Mendelssohn, and Wagner, who appeared about the same time as the leading conductors of their epoch, were, indeed, the first conductor-interpreters. In fact, they founded a new school. I believe that

Wagner was the very first conductor who turned his back to the audience when leading an orchestra. Before him, the conductors stood *à trois quart* facing the public. You may well imagine what little influence a conductor could have on the orchestra, standing with his back to the musicians. But, as I said, at that time the art of interpretation in conducting was not known. The conductors were mostly 'time-beaters' who did not even trouble to rehearse, letting the concert-master rehearse in their stead. Hence, originated the word 'concert-master.' The performance consisted in playing in time, without any consideration to details or perfection. If there was in the orchestra a virtuoso player, and if he had a solo passage to play, he performed his musical phrase with the utmost individuality, disregarding the whole conception of the work, its general meaning or line.

Wagner and Mendelssohn created a real revolution in the sphere of conducting. They no longer 'beat time'; they built up the musical phrase. Yet this, of course, was far from the modern art of conducting. The geniuses of Wagner and Mendelssohn were totally opposite: Wagner was essentially romantic; Mendelssohn essentially constructive. I would say that Mendelssohn's art of conducting is nearer to our day than the art of Wagner, because Mendelssohn's approach to musical compositions is more abstract than Wagner's approach. I would remark that in their time almost the entire young generation followed Wagner, not Mendelssohn, because Wagner reflected his epoch immeasurably more than did Mendelssohn.

It is also interesting to mark the difference of their conceptions of musical compositions. For example, I will take works well known to all of you to show the different renditions of Wagner and Mendelssohn as far as their traditions have reached me. I shall demonstrate:[1]

Allegretto Scherzando from Beethoven's Symphony No. 8:

The tempo of Wagner.
The tempo of Mendelssohn.

Weber, Overture to "Freischütz":

The tempo of Wagner.
The tempo of Mendelssohn.

Which of the two was right?—we can not say.

Here we actually come to the problems of interpretation. Before the World War, interpretative art was strongly influenced by the romantic school. That is, the interpreter regarded a musical composition as an artist-painter would regard a landscape: to him it is an 'aspect of nature.' He takes that 'aspect of nature' and reflects it as he sees, feels, and understands it. Therefore, one and the same landscape in the hands of two artists will have a different reflection. Also the form of one and the same object will be given different lights and shadings.

In all ages, artists were prophets of either the rise or downfall of a culture. In the pre-war period, leading artists introduced decadence into art before it manifested itself in the social and political life of the post-war period. Decadence in musical interpretation in some countries grew to such proportions that not only were the lights and shadings distorted, but the form itself was lost. At the same time, artists in other countries, also instinctively foreseeing that decline, attempted to straighten the distorted line of classical art.

We have a great deal of evidence, however, that musical performers have a right to interpret compositions freely. They hold that right from the composer. Take Bach, for example. In his works we very often find no nuances. Does it mean that Bach intended to have his compositions played without nuances? Positively no. The great Bach leaves that freedom to the performer. Take the classical concertos by Mozart and Beethoven: we find that cadenzas are very rarely written by the composer, who leaves the freedom of improvisation to the performer. In Wagner's scores, after "Tännhauser" and "Lohengrin," we find no exact indication of tempi. Wagner omitted it intentionally, and says in his book on the art of conducting that it is unnecessary to mark the exact tempo, because a talented conductor will find the right tempo anyway; and the untalented conductor will never grasp the tempo even if it is printed in the score. For that reason, Wagner marks his tempi in a general way, such as: "Bewegt," "Massig bewegt," slower, faster, and so on.

I recall a personal experience with the most outstanding contemporary composer, Jean Sibelius. When I studied his Fourth Symphony for a performance here, I found that the tempo of the last 98 bars of the scherzo was marked twice as slow as the preceding tempo,—and that I could neither feel nor understand. I wrote to Sibelius asking for an explanation, thinking that it was a possible misprint and saying I did not feel that tempo. And Sibelius answered: "The right tempo is the one that the artist feels." Where is, after all, the truth of interpretation, and how can an artist justify that truth?

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[1] At this point, passages from the two works were played upon the piano. Mendelssohn's interpretation was shown as faster, more rigid and precise; Wagner's as freer and more emotionally expressive in phrasing.

Personally, I believe that a composer, when creating a work, transfuses it not only with his musical power, but also with the entire meaning of his life—the essence of his being. That is why we can and we must find a 'central line' in the creation of every composer. What is the central line of a composer? It is the meaning of his life and ideals, which he brings to us through the medium of his music.

With Bach, the central line is religion. Bach came to glorify God. And we find in his entire life his praise of God, exaltation of heaven and divinity. Haydn's line is joyfulness, humour, which he wants to share with others. We feel it in every symphony, in every menuetto and allegro. Mozart gives us pure tonal harmony; absolute purity of musical form. If we analyse his creative work, we will find how free Mozart was of any outward influence: he believed in music for the sake of music, sound for sound, beauty for beauty. Let us take Beethoven. His central line is transcendentality: he reflects universal emotion in music. When Beethoven grieves, he grieves with the world; when Beethoven is joyful, it is universal joy; when he feels a tragedy, it is a world tragedy. We can well say that the central line of Beethoven's art is the unifying element of universality. I shall not overburden you by enumerating other composers. But I cannot go by an outstanding figure in musical art—Wagner. The central line of Wagner's art is love and devotion, which we can trace in all his creative work: Love and devotion of Senta in the "Flying Dutchman"; of Elizabeth in "Tannhäuser"; of King Mark to Isolda; of Isolda and Kurwenall to Tristan. And so, we can find in the work of each master a central line expressed in sound.

Here emerges the truth of interpretative art. When the artist-interpreter is able to perceive the inner meaning, the central line, of a composition, he will find in himself the right and illuminating emotion to perform it. It may not be difficult to trace externally the central line, because there exists a vast literature of the life and activity of every composer, especially those belonging to history. It is not difficult for a musician to analyse a score externally, to determine its form, its melodic and harmonic plan, and entire structure. But this only takes us half way; this is only the surface part of the central line, which will give us no true understanding of the depth and emotion of this or the other work or composer. The most important part is that which can neither be read nor learned; it rests in the interpreter himself, in his own emotions, depth, and feeling.

Today, we often hear 'musical authorities' declare, when discussing a performance: "Let music speak for itself." That up-to-date motto is dangerous, because it paves the way for mediocre performers to come and accurately play over a composition from beginning to end, claiming that they "let the music speak for itself." That argument is also not correct because a talented artist, no matter how accurately he follows the markings in the score, renders the composition through his own prism, his own perception of the score, his own temperament and emotion. And the deeper the emotion of the interpreter, the greater and more vivid the performance.

A perfect interpretation may have two different aspects, equally faithful to the score of the composer. One may be called mechanically perfect; the other organically perfect. The first gives the beauty of mathematical balance, symmetry, and clarity; the second is the indivisible, living, pulsating *élan vital* of the composition. One aims to present a beautified surface or reflection of the composition. In the other, the composition—its central idea—lives as a reality. One may be compared to a perfectly symmetrical building; the other to a great Gothic cathedral, with its partly asymmetrical, yet organic order of unity. One is always enjoyable, pleasant and delightful, but remains, like a beautiful scene, external to the listener. The other takes and carries him with the *élan vital* of the work, merges him with the reality of the central meaning, makes him co-live and co-experience the *élan vital* of the composition. Like a mystic experience, the organic interpretation puts the listener in direct touch with the absolute reality hidden in the great work.

Approaching further the question of orchestral performance, I must say that at no time has the standard of musical performance been set as high as it is in America today. This is not a mere verbal statement: facts speak for themselves. In Europe, even in the best of the old days, the symphony orchestras had not nearly the same possibilities as we have here. Nor was there the same intensity of work and interest. I shall take, for example, the Berlin Philharmonic Orchestra, one of the oldest in Europe. How many concerts did that orchestra give in the course of one season under the leadership of a great conductor? In its most brilliant period, the Berlin Philharmonic gave ten concerts with Nikisch conducting. The remaining concerts were led by different and indifferent conductors. Yet, that was the foremost orchestra of the time. A strikingly interesting period of the musical life of Vienna, which may well be termed 'heroic,' is the period when Gustav Mahler was at the head of the Vienna Opera Orchestra. That same orchestra gave also symphony concerts and was then called "The Philharmonic." However, it was, in the first place, an opera orchestra, the concerts came in between; there were, perhaps, eight o ten symphony concerts in a season, also conducted by various conductors. The possibilities in America are infinitely better, and give a new idea of orchestral performances.

It is a mistake to think that musical life in America develops only because of America's wealth. This is wrong. Musical life in this country grows because there is the need for music. That need for music today has an explanation: men seek an outlet for their best and deeper emotions, and they find it in music. For music is the recovered word of true feeling liberated from the banality, hypocrisy, and cruelty of life. Music is to help the souls of men It is the pure language, regenerating, like the mountain air.

AMERICAN POLICIES IN THE FAR EAST

By W. Cameron Forbes

Presented December 8, 1937 Received March 8, 1938

The relationship between trade and national policies is so intimate that I do not feel that one can get the proper comprehension of the one without a fairly complete understanding of the other.

As a preliminary measure of approach to my subject I have assembled figures showing the course of trade between the United States and the more important countries of the Orient; and others giving a picture of the general conditions and the division of the political spheres of influence in the Pacific.

I should like my readers to try and visualize the geographic relationship of the United States and the countries that border the western Pacific Ocean, commonly spoken of as the Far East. China is a vast territory with an estimated population of 450 millions, very unevenly distributed, as there are areas of very dense population and other vast areas rather sparsely populated. Japan, with a population of 85 millions, owns a fringe of islands running from the ice-bound areas in the neighborhood of Kamchatka in the north, to Formosa in the south and including Korea on the continent of Asia.

Asia is virtually fenced off from the Pacific by some 3,000 miles of islands of which probably two-thirds now pertain almost entirely to Japan; the lower third consist of the Philippine Islands with probably 18 millions of people in an archipelago 1,200 miles in length and comprising something like 8,000 islands of which about a thousand are inhabitable and inhabited.

A study, however, of the control exercised by the different countries over the scattered islands of the Pacific shows how unwise our policy was at the close of the World War in having permitted practically all of the scattered groups of islands controlled by the Germans to pass over to the hands of the Japanese on a mandate of the League of Nations. Proper protection of American interests would have insisted on a reasonable parallel of latitude above which Japan would have control and below which the series of islands would have passed to the United States, thus giving us a continuous trade route to our own possessions, namely the Philippine Islands, and the shores of Asia, and to the great populations that lie on the western and southern parts of Asia. By reason of the possession of such a chain of islands, they would be available for use as ports, fueling stations, naval bases, and landing fields for our airplanes.

The historical sequence of events in connection with trade to the Orient is too long a story to recount. We all know the international race for trade relations with China carried on centuries ago, principally by the British, Dutch, Portuguese, and Spanish adventurers long before the United States became a nation.

With the beginning of the last century Americans began to interest themselves in the Chinese trade, and a few hardy adventurers established their houses in what were called "treaty ports," in the few spots in China where foreigners were allowed to carry on business.

In the early part of the last century one of the most noteworthy houses was that of Samuel Russell & Company, founded in 1819, and which in 1834 became the house of Russell & Company. My grandfather, John M. Forbes, became one of the leading figures of the concern before he had reached his twentieth birthday, and later at the age of twenty-one found himself head of the house with headquarters in Canton. Russell & Company operated largely under the direction of succeeding members of my family until 1891 when it finally went out of business under that name.

The glamor attached to the house still lingers, and when I went out to the Philippines in 1904 to join the Philippine Commission, and on various trips since, I have become conscious of the fact that the Chinese still remember the name of that house and its prestige. On my last visit there in 1935 one of the highest officials in the Chinese government expressed the hope that the old house would be brought into existence once more with some of its former support.

The story of the early days of Oriental commerce is inextricably concerned with the glamor of the clipper ships and their captains. A captain had not only to be a sea captain but a merchant capable and ready to handle the disposition of cargoes, and the taking on of others. The decision of the captain had to control, and the names of some of our most distinguished citizens of today are to be found in the lists of sea captains who sailed forth in those days on their long, and sometimes hazardous, journeys. To digress for a moment, I remember hearing from his own lips, Captain Clark, the author of "The Clipper Ship Era," tell of a time when he found himself short of fuel on a voyage in which he was taking a steamship to China on behalf of my grandfather. He had to cut up the interior woodwork of the ship and use it for fuel in order to bring her to port. The cost of replacing the interior woodwork of the steamship, by cheap Chinese labor, was trivial compared with the loss of a market he would have incurred had he put into some way port for fuel. He knew he must be the first ship to reach China with that cargo. Captain Clark recounted to me the laconic words of my grandfather that greeted him years later on his return: "I was pleased with the way you handled my ship."

The history of Chinese international relations is not wholly a pretty one. Country after country has taken advantage of Chinese lack of cohesion to get improperly favorable concessions, often exclusive in character and some have gone as far as to carve off pieces of its territory. The British took the important port of Hongkong which, under their wise trade practices, has become one of the greatest ports of the world in the matter of tonnage. The French seized Indo China, and the Portuguese still possess the port of Macao which, while not comparing with the others, still is an avenue of approach to Eastern Asia.

The former Chinese system of administering justice, and their harsh way of dealing with their own people, torturing witnesses, prisoners, etc., and the low value the Chinese put on human life, giving death sentences for what to the Occidental mind are trivial offences, made it impossible for other nations to be willing to subject their citizens to Chinese courts or prisons, or to receive trial or punishment under the Chinese penal code. This had resulted in the various nations using force to compel the Chinese to permit courts to be established in areas that are known as international settlements within the boundaries of certain ports, called "treaty ports," the most important of these being Shanghai, where the international settlement is governed under what are known as "regulations." There is also an international settlement at Tientsin, and at the legation quarter at Peiping, where the various diplomats of the governments are domiciled and where they maintain a guard. In Shanghai and at Tientsin there are troops maintained by the United States, Great Britain, Japan, and other countries that have settlement areas.

These courts, under a system called extra-territorialty have jurisdiction over cases that arise between the Chinese and the citizens of foreign countries. Where no international settlements exist such areas were handled in consular courts under the control of the consuls of the countries whose citizens were concerned.

In early days consular courts were existent in Japan, and the closing of these courts and the submission of all cases to courts wholly under Japanese jurisdiction was a matter of long negotiation. Extra-territoriality in Japan was relinquished by the United States in 1889.

In China extra-territorialty still lingers although in a modified form, but it is a cause of constant resentment and agitation among the Chinese. And the obvious unfairness of submission of judicial matters to a consular court in which the Chinese have no participation or voice is sure ultimately to do away with that system. These probably will be succeeded by special courts where cases involving foreigners will not be subject to the penal laws of the Chinese even though they be modified and modernized.

The United States has never sought and never obtained or controlled any area of Chinese territory, except that they shared with other countries in the management of Shanghai; they have an American area in that city over which they exercise jurisdiction but over which they hold no sovereignty. Ever since the so-called Boxer Uprising, the United States has maintained a force of troops in the concession at Tientsin as well as a Marine guard at Peking for the protection of diplomatic representatives.

It is an interesting fact which I got from no less a source than the lips of the late President, Mr. Taft, that in the early days of the Chinese Republic the Powers had about agreed to form the re-establishment of the monarchy in China, and that it was the United States which had dissuaded the Powers from this.

Coming now to a study of our statistical data, I am sorry to say they reveal a grievous decline in the American merchant marine. In the early part of the 19th century ninety per cent of our foreign trade was carried in American bottoms. A hundred years later it had dropped to less than ten per cent. And, in spite of the means taken to restore it, it has now reached only about forty per cent. Moreover, I have been informed that we have allowed a large part of the present fleet to approach obsolescence, without proper provision for keeping abreast of modern construction and modern requirements; and we are faced with a heavy construction program if we desire to keep ourselves even at our present unsatisfactory level.

American trade with the Orient begins with the early part of the 19th century and shows a moderately steady line of increase to the beginning of the 20th century, at which time commercial history, insofar as it concerned American policies in the Orient, may be said to have begun.

In the early 1800's, when trade with the Orient was young, it amounted to about seven per cent of the total foreign trade of the United States. From that time it gradually rose to the highest level in 1931 when it reached 17 per cent; and the latest figures indicate that, at present, it is somewhere between 13 and 14 per cent. In other words, over 85 per cent of our foreign trade is with other countries than the Orient. As these Oriental countries comprise nearly half the population of the world, the inference is clear that there is a potential trade awaiting development when the internal conditions of these countries are ready for it, and when we have learned to capitalize and develop our opportunities.

My figures are all in dollars, and it must be observed in studying these figures, that fluctuations are quite likely to be induced by sharp changes in price with comparatively small fluctuations in tonnage. This is noteworthy in studying the trade with Japan, where the gross value of our silk imports fell off 66 per cent while the tonnage fell off only about 20 per cent.

Our figures show that trade in the 19th century with China, while steadily growing, had not reached major proportions.

Commerce with Japan was non-existent in the first half of the 19th century. It owed its beginning to the visit of Commodore Perry in the 50's, at which time he persuaded the Japanese to abandon the age-old policy of isolation and to admit foreign commerce and visitors to their shores. Commodore Perry's voyage is now history. His representations to the Japanese government resulted in Townsend Harris, first as an agent and then later with the title of consul, opening the first commercial and diplomatic American office in Japan in January, 1859.

It was not until late in the year 1870 that the American representation in Japan was elevated to the rank of minister with the title of envoy extraordinary and minister plenipotentiary. In January, 1906 the representation was changed to that of ambassador.

In 1898 the war with Spain broke out and the United States captured the Philippine Islands, and by the Treaty of Paris became the possessor of these Islands by concession and purchase from Spain. But for the ensuing three years the Islands were in a state of insurrection against the United States and trade naturally suffered.

In 1909 the so-called Payne Bill, providing for the free exchange of commodities between the Philippine Islands and the United States, became law. The ensuing trade relations reveal conclusively the stimulating effect of free trade. It leaped from 15 millions to 45 millions within three years, and then it went progressively on until it reached the high point of over 200 millions at the time of high prices and abundant commodities. From then on it gradually eased off, and now it holds at about 150 millions a year, or ten times what it had been before free trade began.

Coming now to the 20th century, our statistics reveal an almost startling increase in the trade between the United States and our nearest Oriental neighbors. That with China reached the high point of 350 million dollars in one year, namely, 1920. That with Japan reached 700 millions in 1929. And that with the Philippine Islands, as before stated, nearly 200 million dollars a year.

In all these cases there have been sharp recessions explicable in part by the reduction of prices rather than tonnage of goods shipped, as described above. As the present range of prices seems fairly normal, it is not to be expected that, without new development, trade with these countries will carry on at anything like the level of the highest points previously reached.

It is instructive to analyze these figures of commerce and see what commodities make up our principal exchanges with each of the countries concerned. For instance, our purchases from China of the greatest commercial value are: raw silk, skins and furs, tung oil, flax, hemp, ramie, and carpet wool. Whereas China buys from us raw cotton, petroleum products, iron and steel products, automobiles, busses, trucks, tobacco products, and industrial and electrical machinery, all expressed in the order of their importance.

The United States buys from Japan an amount or raw silk the value of which has reached in one year as high as 350 million dollars, which exceeds the sum of all the rest of the imports together. The predominance of the silk trade is indicated by the fact that in the same year no one of the next four items in importance reached 10 million dollars. Japan's export of silk runs about 60 per cent of her total exports to the United States. From a high point of over 300 millions of dollars our imports of silk fell to about 75 millions within five years; this was a great blow to the Japanese producers, and was largely the result of the fall in price, partly attributable to the substitution of rayon for real silk. In this connection it is interesting to note that the Japanese have met this situation by going extensively into the production of rayon. Japan also has been shipping an increasing amount of manufactured cotton goods to the United States.

It is an interesting fact that the Japanese can purchase raw cotton in the United States, transport it to Japan, manufacture it into textile goods, send it back to the United States, pay the duty, and still undersell the product of our mills. The reason for this is the extremely low wages in Japan, amounting to about one-tenth of what our people require and receive, which not only affects the operation of spindles but means a much lower capital cost as the item of labor is the largest single item that goes into construction, and these low costs in Japan are naturally reflected in the capital investment in their buildings and plants. Even the prices of materials that go into these structures, such as brick, tiles, lumber, structural steel, etc., reflect the rate of wages prevalent in Japan, because the cost of these materials is largely, but not wholly, influenced by the labor element involved in their production and transportation.

The exports from the United States to Japan include raw cotton, iron and steel products, petroleum products, electrical machinery, and automobiles, busses, and trucks.

The Philippine Islands are naturally and normally a great economic asset to the United States, producing as they do articles which we consume in quantities and which we cannot produce ourselves, as within the continental boundaries of the United States there is to be found no tropical area.

Sugar has acquired a dominance of the Philippine export trade which far exceeds all other exports. It has reached as high as 66 millions in one year.

Except for a small production in Louisiana, almost all the rest of our supply of cane sugar is imported from Porto Rico, Hawaii, and Cuba.

The United States produces an important part of its sugar requirements by the manufacture of beet sugar. In several western states beets grown for this industry have come to be a major agricultural product. These states have come to believe the competition of Philippine sugar is inimical to their best interests and hence their representatives in Congress have joined those who, for other reasons, desire complete political separation of the Philippines from the United States.

Sugar is by far the largest item sent from the Philippines to the United States, amounting to about two-thirds of the total export trade. In my opinion it was highly unwise, from a political point of view, for the Philippine administrators, American and Filipino, to have allowed one commodity to so largely exceed all other articles of export. This was too much like putting all one's eggs in one basket, especially one that at any time might be subject to tariff changes or quota limitations.

The Philippine economic situation would have been much safer and less subject to attack if, from the beginning, a fixed quota of ten to twelve per cent of our total consumption had been allocated to Philippine sugar.

The other commodities that the Philippines produce are: the products of the coconut, which is sometimes exported in the form of coconut oil which is refined in the Islands, and copra—the dried meat of the coconut—which reaches nearly $45,000,000 (1929) in high years. Next comes Manila hemp of which, until recently, the Philippines have had practically a world monopoly, as in no other country has hemp come to be grown extensively. Hemp is allied to the banana plant and it is very possible that the banana-growing countries to the south of us will develop the hemp business and become serious competitors of the Philippine Islands in what had previously been a monopoly. Indeed a start has been made in that direction.

Philippine exports of tobacco reach the moderate total of three million dollars a year. An interesting fact in this connection is to be found in the circumstance that the Philippines buy from the United States nearly 80 per cent as much tobacco products (mostly cigarettes) as they sell to us.

Now what do the Philippines buy from us? The largest item at the present time is petroleum products, and after that iron and steel products, cotton goods, electrical and industrial machinery, and finally antomobiles, trucks, etc.

Recent figures reveal the degree to which we have lost our market in the Philippines for cotton fabrics, which in 1920 is shown to have reached the high figure of 20 millions of dollars, and this year (1937) it is running about a quarter of that.

The Philippines is one of our most noteworthy consumers of dairy products. In 1936 they purchased from us something over half of the total dairy products purchased from us by all other nations, having purchased $3,652,000 worth from us in 1920; but in 1935 and 1936 this had gone down to $1,538,000 and $2,034,000 respectively. This is particularly significant in view of the fact that the representatives of the dairy interests have been very active in opposition to the retention of the Philippine Islands by the United States and favoring independence, due to the mistaken idea on their part that the Philippine Islands were a menace to their own industry.

There has been a rather clever lobby maintained by the sugar interests to exclude the Philippines from within the tariff boundaries of the United States. This lobby has deluded the representatives of the United States' farm interests into believing that coconut oil, which is used for making artificial butter, was a serious competitor. Better informed people deny this and I think, personally, that there has been something in the nature of skullduggery in the thing.

CHINA

In an effort to preserve the integrity of China and halt the rather hectic scramble of countries to get unduly favorable concessions, some of which were strongly suspected of having been obtained by corrupt arrangement with high Chinese officials, Secretary of State Hay in 1899 enunciated what has come to be known as the "Policy of the Open Door."[1] The exact phraseology is as follows:

> ". . . to seek a solution which will bring about permanent peace and safety to China, preserve China's territorial and administrative entity, protect all rights guaranteed to friendly powers by treaty and international law, and safeguard the principle of equal and impartial trade with all parts of the Chinese Empire."

On the 6th of February 1922 the so-called Nine Power Treaty was signed in Washington, with the following signatories: The United States of America, Belgium, the British Empire, China, France, Italy, Japan, the Netherlands, and Portugal. I will quote the first article:

"The Contracting Powers, other than China, agree:

(1) To respect the sovereignty, the independence, and the territorial and the administrative integrity of China;
(2) To provide the fullest and most unembarrassed opportunity to China to develop and maintain for herself an effective and stable government;
(3) To use their influence for the purpose of effectually establishing and maintaining the principle of equal opportunity for the commerce and industry of all nations throughout the territory of China;
(4) To refrain from taking advantage of conditions in China in order to seek special rights or privileges which would abridge the rights of subjects or citizens of friendly states, and from countenancing action inimical to the security of such states."

In Article 2, the Contracting Powers agree not to enter into any treaty contrary to the spirit of Article 1.

Other articles are interesting only as to matters of detail.

The Pact of Paris, or the so-called Kellogg Pact, named after Mr. Kellogg, the Secretary of State, Japan being one of the Contracting Powers, sets forth:

> ". . . the time has come when a frank renunciation of war as an instrument of national policy should be made to the end that the peaceful and friendly relations now existing between their peoples may be perpetuated."

Article 1 solemnly condemns recourse to war.

Article 2 sets forth that the settlement or solution of disputes should never be sought except by pacific means.

All this is interesting in view of later Japanese invasions of China.

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[1] On September 26, 1899, Mr. Hay defined in detail the exact significance of the Open Door in a letter to the Ambassador of Germany.

JAPAN

The history of Japan is one of slow emergence of the democratic from the feudal system.

Shortly after the opening of Japan to trade in 1889, the enlightened Emperor Meiji sent some of his most promising young men to obtain their education in the United States, and, later, sent some capable diplomats and administrators to study Occidental civilizations. These men profoundly influenced Japanese development, and little by little the commercial and intellectual classes have been rising in the esteem of the community and are coming more and more into their own. The greatest step was taken when the Diet, or lower house, of the legislature was established with control over appropriations.

The power of the sword, however, still lingers. In the old days of the Samurai, the "two-sworded man" was the cock of the walk; all others bowed before his power. As used to be the case in England, merchants, tradesmen, and men of business belonged to professions which were regarded as more or less degraded in the eyes of the war lords and the populace.

What is left of this feeling accounts in large measure for the predominance of the military today in Japan. Controlling as they do the armed forces of the nation, including the navy, the people of Japan live in jeopardy of a military coup.

The history of American dealings with Japan, beginning with the middle of the 19th century when Japan's centuries-old period of isolation came to an end, and following the opening up of diplomatic relations, has been one of constantly growing trade and of a tendency of Japanese laborers to flow into Hawaii and the western shores of the United States. The Japanese, contrary to the prevailing impression, are not natural colonizers; they have, for instance, made almost no emigration into the annexed territory of Korea, and even less into Manchuria. The few Japanese that have emigrated have usually been merchants, tradesmen, and managers, and not workers of the soil. The Japanese enjoy a higher scale of living than do the Koreans or natives of Manchuria and make no effort to compete with their agricultural classes. Nor have they flowed in any quantity to Formosa and the southern islands over which the Japanese have a mandate. There has been no great exodus to the semi-tropical countries of South America into which, until recently, there have been few restrictions as to Japanese admission.

The west coast of the United States, however, with its high wages, easy living conditions, rich soil, and abundant markets was a veritable paradise for the thrifty Japanese. Hawaii, also with its delightful climate, became a particularly desirable place for the Japanese laborers to acquire wealth. The native Kanakas were an easy-going type, not given to hard work, and the sugar planters had been hard put to it to secure laborers for their plantations. When the Chinese exclusion act became effective for Hawaii, the Hawaiian sugar planters were deprived of that prolific source of competent labor. It was natural that they should turn to Japan whence they presently drew a population which became numerically by far the largest labor element in Hawaii.

When the Hawaiian Planters Association realized the Japanese population had assumed such proportions that made them a menace, they sent an emissary to the Philippine Islands, to enter into an arrangement for the substantial movement to Hawaii of Filipino laborers. Mr. Judd brought his credentials to me and I collaborated with him in his labors. The move succeeded, and the Filipino population of Hawaii has reached the substantial figure of 55,000 at last accounts, whereas the Japanese population has remained practically stationary at about 150,000. Among those listed as Japanese, however, are many who have become thoroughly Americanized in habits of thinking and living, and now include a second and third generation born in the Hawaiian Islands. In the matter of dress, houses, food customs, they have adopted all the aspects of Occidental civilization. I was informed by one of the Governors of Hawaii that he believed that in case of war between the United States and Japan that many of these born or naturalized American-Japanese would side with the country of their adoption.

Meanwhile, the Japanese had swarmed over the Pacific coast of the United States and the Japanese population of California was estimated to exceed 175,000, and that of the whole Pacific coast something over 250,000. This was not without its difficult aspects. The industrious Japanese could live more cheaply and were willing to work harder and work longer hours than the laborers of other nationalities or native Americans. Competition got very keen. Feeling began to run so high in California as even to menace public order. Theodore Roosevelt met this situation by what was spoken of as a Gentlemen's

Agreement with the Japanese, by which they volunteered to check the flow of laborers into the United States. Under this arrangement very few trickled in; and this agreement remained in force until May 26, 1924.

In that year the United States Senate was considering immigration problems, and the question of a rigid exclusion of the Japanese laborers was under discussion. Mr. Hanihara, the Japanese Ambassador, a competent and earnest diplomat, sent a most unfortunate message to our Secretary of State, in which he made what our Congress took to be a threat that if this bill passed "serious results" were likely to ensue. It has been said that this proposed message was shown to some officer in the State Department for comment before delivery, and that when read he failed to caution the ambassador as to its probable affect.

Our Senate almost immediately, and rather petulantly, passed drastic legislation prohibiting all Japanese immigration. This is still in effect.

The move was unfortunate and undiplomatic, and was so resented in Japan, and feeling ran so high, that for a while even the lives of Americans in that country were in danger. America's best friends among the Japanese—men like Viscount Kaneko, a Harvard graduate, who has been President of the Japan-America Society of Tokyo; the learned and virtuous Doctor Nitobe; and others—became bitterly incensed and the cause of friendly relations between the two countries was seriously strained.

Our people could have been amply protected by a quota system, such as prevails in dealing with other countries, under which only one or two hundred could enter the country each year. The Japanese government would have cordially cooperated to hold their emigrants to these figures and to prevent undercover practices by which more Japanese probably get into the country now than would have come in under a quota system.

Upon my appointment as Ambassador to Japan I set myself the task of endeavoring to rectify this unfortunate situation. I found the Chambers of Commerce on the Pacific coast cities were strongly in favor of putting Japan on a quota basis. I attended meetings of the chambers in Los Angeles, San Francisco, and Seattle, and found in each of these bodies that the feeling was practically unanimous in favor of this move. There was, however, a small party of irreconcilables, with a leader who was almost fanatical in his bitterness against the Japanese, which was organizing groups in the labor unions, The American Legion, and other organizations to oppose any change in the law.

This was the situation when the Japanese invasion of Manchuria took place in 1931. Since then the friends of Japan have deemed it unwise to even broach the matter in Congress. It is to be hoped that some day this matter will become adjusted so that a moderate quota system may extend not only to the Japanese but also to the Chinese.

Hostility on the part of Pacific coast Americans to the Japanese manifested itself in other ways: the latter were prohibited from taking American citizenship; they were discriminated against in the matter of public schools, and in the securing of titles to land.

When Governor Wright was ambassador to Japan, in the course of certain negotiations in which the Japanese government was protesting against these discriminations, Governor Wright, who was one our ablest and most adroit lawyers, countered by calling their attention to the fact that there were in existence certain Imperial decrees of long standing precluding foreigners from getting the very privileges of which the Japanese themselves were then objecting to their citizens being deprived of in the United States. These timely disclosures, which greatly surprised the then Foreign Minister, stopped all further critical comment.

On their behalf, it may be said, that on the whole the Japanese citizens along our Pacific coast have been very good citizens; they are hard-working and industrious; and the Governor of California and the mayors of the cities with large Japanese populations have spoken in high terms of their law-abiding characteristics.

I have previously spoken of the possibility of a coup d'état on the part of the Japanese army. This would take the form of an uprising, actually not against the Emperor but against his advisors. The respect of all classes of Japanese for their Emperor is such that all elements would unite in holding his person inviolate, but that is not true of the persons of his officers and advisors as has been demonstrated no less than four times by murderous outbreaks within the last decade.

The assassination of Prime Minister Hamaguchi came first, as a protest against what the Navy regarded as an unfavorable treaty agreed to by the Japanese cabinet. A little later one of the Emperor's most conservative advisors, who had been Secretary of the Treasury, fell from an assassin's bullet. A little later still the extremely able managing head of the great financial house of Mitsui was killed. Authorities got evidence that there was a so-called "Death Gang," and that eight or ten of the leaders and close advisors of the Emperor were marked for death. Active work by the authorities prevented further assassination but in a subsequent outburst the assassination of the then Prime Minister took place.

Still later another recrudescence of this same type of conspiracy resulted in the shameful slaughter of the octogenarian Takahashi, Secretary of the Treasury, and of the wise and kindly Viscount Saito, an ex-prime minister and one of the Emperor's wisest, ablest, and most accomplished advisors.

In the trial of the men concerned in the assassination of Prime Minister Inukai, one of the conspirators informed the court that he had intended to assassinate the American Ambassador in the belief that it would stir up enough feeling between the United States and Japan to compel the material increase of the Japanese army and navy.

Fortunately, I had already left for America before the would-be assassin was released from a hospital in Shanghai where he was recovering from wounds.

When I speak of the possibility of a coup d'état I am speaking not as an alarmist, for it is a real and present risk. In fact there was one attempted while I was ambassador. The details were hushed up and the conspirators were dealt with in a way that was felt to be very lenient,—by merely being sent off to scattered and distant posts.

The Japanese military element now in power is said to be dominated largely by a group of young officers who are believed to be in large measure responsible for the recent happenings in China.

The better civilian element in Japan is not sympathetic with this situation. The merchants, financial magnates, and the intellectuals—university presidents, professors, and the literary and artistic people of Japan—are greatly concerned over this situation. There is good reason to believe that they would break it up if they had the power to do so.

We come now to the episode of September 18, 1931. The Japanese, as a result of the war with Russia, had secured the management of the South Manchuria Railway, with its grant of land. They had succeeded in moving 180,000 Japanese into Manchuria in the 27 years since the war, while the Chinese influx into the rich plains of Manchuria from the overcrowded regions to the south reached the princely total of ten millions. The estimated population of Manchuria at that time was 30 millions; this includes 800,000 Koreans who claimed Japanese or Chinese citizenship according as it suited their convenience. It will be seen that the total number of citizens in Manchuria that the Japanese could lay any claim to with respect to sovereignty did not exceed a thirtieth of the population.

The Government of Manchuria was weak, backward, and unable to maintain public order; the finances were chaotic, and the currency indicated the abundant activity of the printing presses. The Japanese, with their billion dollar investment in this region, were unable to get protection or consideration of their demands, partly because the Chinese government was not strong enough to provide the required amount of protection or to force its own people to carry out its undertakings. It was a situation that could only be solved by force and the Japanese military leaders, probably finding it impossible to get the civil element in the Japanese government to assent to an intervention and invasion of Manchuria, staged what is generally believed to have been a framed-up episode, namely, the breaking of the South Manchurian Railway during the night of September 18th by what they claimed were Chinese soldiers. That the break was not serious is proved by the fact that an express train passed over it without mishap later the same night.

One of the American assistant military attaches who was in Manchuria at the time witnessed maneuvers by the Japanese army simulating the investment and capture of Mukden which was staged two days before the actual capture took place, which indicates convincingly that the whole move was absolutely premeditated.

Using this episode as an excuse, the Japanese army invaded Manchuria, captured Mukden, dispersed the garrison, got control of the arsenal and the banks, and then for the next year they hurled forces of the Japanese army, supported by airplanes, against any assemblies of Chinese troops to be found in any part of what was then known as Manchuria.

Every Japanese attack as carried out, and each new invasion of Chinese territory, was heralded as being done in the name of defense. Each offensive movement was justified to the world as being purely defensive.

After the whole of what was known as the three northern provinces, and generally called Manchuria, was occupied, the Japanese began moving into the neighboring provinces on the west, which they claimed belonged to Manchuria.

When the American Ambassador asked one of the Japanese magnates for a map showing what he would regard as the boundaries of Manchuria, he was laughingly told they were "indeterminate." The facts were that the Japanese army proposed to push west as far as they could without coming in contact with the Russians who claimed a sphere of influence in what is known as Outer Mongolia, the "indeterminate" line being the limits of what was commonly known as Inner Mongolia, or as far west as the Russians would let them come without actual hostilities. Before a line was actually determined upon there were actual clashes between Russian troops and those of the new state which the Japanese had set up in Manchuria, which they called Manchukuo.

I do not want to convey the impression that the people of Japan generally were opposed to the whole Manchurian episode; they were not. The best opinion that I could get among the more enlightened civilians, including especially industrial leaders, was that close association with Manchuria and the retention of the South Manchuria Railway was necessary for Japan if they were to maintain their position as a first class power. They called it "a life line" to the continent of Asia as it gave them a normal avenue of approach to the great populations and markets of Asia.

Their criticism, which had to be veiled if they valued their lives, was, as is mine, against the manner and extent to which the controlling army group have carried their rough tactics, their disregard of treaty obligations, and the interference with the sovereignty of China brought about by the existing Japanese arrangement with Manchukuo.

Shortly following this conquest of Manchuria by the Japanese, hostilities broke out in Shanghai. This episode was probably fortuitous as the best evidence is that it was not planned in advance by the high command either of the army or the navy. It was brought to a head by a hot-headed admiral of the navy who was in charge at the time, and who was later relieved. The whole campaign was very futile. It involved unnecessary destruction of an important part of the native city of Shanghai outside of the International Settlement and resulted in no compensating improvement in the situation.

The Chinese army made an heroic stand but was finally pushed back by the arrival of a large Japanese reinforcement. Later the Japanese withdrew and things returned nearly to *status quo* in that region. The Japanese had obtained no worth while objective by the episode, and they had lost much of the good opinion in which they had been held by neutral countries the world around.

JAPAN—STIMSON—MANCHURIA

I come now to the part taken by the United States under the leadership of Mr. Henry L. Stimson, Secretary of State. In his recent publication called "The Far Eastern Crisis," Mr. Stimson several times sets forth, in clear and convincing phrases, that the situation required that "no steps should be taken which would make his (Baron Shidehara's) task more difficult." Baron Shidehara was the able and conservative Minister of Foreign Affairs at that time.

It seems strange that with so explicit an understanding of the course to have been pursued, Secretary Stimson should have proceeded along lines that accomplished the exact opposite of what he declared the situation required, and which, as Baron Shidehara, speaking of its effect on him, said to me, had "made his position untenable." This was done by repeated notes, press releases, and the publication of letters, which, in the opinion of Japanese friends of America and of Americans and others in Japan, were sharp and even provocative in tone.

The position taken by the United States was absolutely correct; it was the tone and the frequency of official notes, etc., that caused a feeling of such tension that I have it on the authority of one of the best-informed Japanese statesmen that we just barely missed an open break with Japan at that time.

Moreover, these notes had the definite effect of making the Japanese people feel that the United States was their especial enemy, which was exactly what their military leaders wanted to achieve.

In my journals, referring to the assassination by one of the Death Gang in Tokyo of Baron Dan, the head of the great house of Mitsui, I find this comment: " 'Give us time,' he said, over and over again. 'We will work this thing out'; but he begged me most earnestly to have the outside pressure stopped. Finally, when it seemed I'd done so, he shook my hand repeatedly and most warmly, his face all smiles. It was only a few hours after that that he was murdered."

A quotation or two from a volume written by a Lt. General of the Japanese army, and published at about that time and fairly widely read in Japan, will show how feeling was being stirred up against our country: Speaking of the people of the United States, he says:

> ". . . We must hate these devils in human form with human faces and animal minds. . ."
>
> ". . . For the sake of moral righteousness, we must appoint ourselves the agents of heaven, and we must punish and chastise these people. . . . ."
>
> ". . . By force of circumstances, we will be obliged to go to war against America in the end. A Japanese American war is the unavoidable fate of our nation."

In November, 1931, the Dutch and the Norwegian Ministers in Tokyo called on me in my capacity as ambassador, and expressed the conviction "that the less outside pressure exerted upon Japan the better it would be for the situation." There were 29 countries represented by ambassadors, ministers or chargés d'affaires, and I was assured that every member of the diplomatic corps felt the same way about it. The reasons given were that the Oriental mentality was such that it was dangerous to force any Oriental people into supporting a policy in order to save face.

Without having received any request by the Japanese to recognize Manchukuo, on June 7, 1932, Secretary Stimson took occasion to send a note, which in view of the inflamed state of public feeling in Japan, was regarded by the diplomatic representatives of all the nations there as highly inopportune.

In this note he announced that the United States "can not admit the legality of any situation *de facto* nor does it intend to recognize any treaty or agreement entered into between those governments (China and Japan), which may impair the treaty rights of the United States or its citizens in China."

Secretary Stimson in this message took what I think is an untenable position when he said that the United States "would never recognize" a situation created contrary to the provisions of the Kellogg Pact, i. e., created by force. It should be remembered that the assertion was tossed out to a world made up of nations, many of whom occupied situations created by the re-assignment of boundaries following the World War.

The determination not to recognize Manchukuo was the only one our country could have taken at that time. Nor would a refusal to do so have been resented by the Japanese if they had asked it. They hadn't.

Following the Manchurian episode, a Mission composed of one representative each of the United States, France, Germany, and Italy, under the presidency of the Earl of Lytton, after carefully studying the Manchurian situation made a report to the council at Geneva on the first of October, 1932.

Our representative on this Mission was General Frank R. McCoy, in my opinion, our ablest diplomat.

This report, which was dignified, statesmanlike, and practical in its suggestions, found in the main that China, while not wholly and thoroughly organized, was making satisfactory progress towards unity and organization, that the Japanese claim that their movements in Manchuria were in self defense were not justified by the facts, and that Manchuria was and should be an integral part of Chinese territory. They did not recommend the return to the *status quo ante* but devised a statesmanlike solution which would protect Japanese legitimate interests in Manchuria.

In my judgment, the Japanese government made a capital error in not accepting the report with avidity. They would have done well to have ignored the critical comment contained in the report, placing the responsibility for their aggressions upon the military clique.

MANCHURIA

We have found that the representations of the Japanese have not always squared with their deeds. They declared, for instance, definitely and pointedly, at the time of the invasion of Manchuria that they would respect the Open Door Policy. In spite of this declaration they proceeded to make it so difficult for American concerns doing business in Manchuria as effectually to put them out of business there. This was notably true of financial institutions and of those engaged in the petroleum industry. Under the pretext of a government monoply in petroleum they practically closed up the oil companies doing business in Manchuria, British and American.

As ambassador in Tokyo I had occasion to receive first hand information in regard to these operations from representatives of concerns that were being hurt. More than once I took occasion to make representations to the Japanese Foreign Office, which proved to be totally impotent to take remedial action as they had to confess that during the period of disorder, as they called it, these matters were under military control. The best I could get out of them was the expression of their belief that, with the restoration of public order, business would return to its normal course; this has not occurred. As some careful observer expressed it: "While the Japanese adhered to the Open Door Policy, they stood in the door." While some business, such as that of automobiles, continued, they were careful not to let business that competed with their industries get much of a foothold.

While I have said that the Japanese had genuine grievances and hence some justification for their invasion of Manchuria, they will have hard work to justify to posterity the manner in which they conducted their operations, their roughness and, if abundant evidence is to be believed, the venal nature of their officers and administrators, who used their positions to force drugs and narcotics on the Chinese population in occupied areas. The Japanese army also assumed control of North China ports and abused their control of customs to force the Chinese to receive Japanese goods on which the regulation Chinese duties had not been paid.

Whatever justification there may have been for the Manchurian episode there is no justification whatever, in my opinion, for the present shocking invasion of China. The reasons given by the Japanese apologists are preposterous and I do not think their arguments carry conviction to one in a thousand of fair-minded people. The unanimous condemnation of the Japanese aggression by the League of Nations in council assembled shows that this feeling is not confined to one country. The whole world is looking with horror upon the slaughter of so many defenseless Chinese and, in the interests of Japan, I think all right-minded people should hope that they will have no success or realize any advantages from this iniquitous venture.

China can not expect armed intervention on their behalf by neutral countries. There is, however, an economic penalty being placed on Japan as a result of world-wide disapproval of these acts which must be making itself strongly felt in the consumption of Japanese products. It is probable that if private citizens the world over deprive themselves of the use of articles of Japanese production or manufacture until such time as Japan shall have withdrawn from China, it will hasten materially the return to reason of its deluded people.

PHILIPPINES

The acquisition of the Philippine Islands by the United States had no commercial or economic basis and was brought about merely by the chance fact that the American Asiatic Fleet, under Admiral Dewey, found itself in Hongkong, a neutral port, at the time of the outbreak of war between the United States and Spain and, according to international usage, had to put to sea. The Philippines were within easy sailing distance and Admiral Dewey conducted his masterly operation of running by the forts at Corregidor and destroying the Spanish fleet and investing Manila.

Space will not permit me to give the details of the pacification of the Islands. Suffice it to say that the elements that had been in insurrection against Spain, and were pretty well organized in the field, soon found themselves engaged in a long and costly insurrection against the United States, which was put down at the expense of a good deal of blood and treasure. Some of us who went out later in administrative capacities and came to know how to deal with the Filipinos came away feeling that all of this grief could have been averted had the United States had adequate preparation in the way of transports and trained men to handle the situation; that, however, is crying over spilt milk.

The civil administrators went out to the Philippines headed by the wise and magnanimous Mr. Taft, who tried to salve the sore places and make friends with the Filipinos.

The Americans did the best they knew how to give the Filipinos a good government. It was inevitable that our untrained administrative officers, having to deal with an alien people talking a variety of strange languages and of different habits of thought and living conditions with which no Americans were yet familiar, should have made numerous mistakes and it is to their credit that they didn't make more. In spite of these, the story is on the whole a creditable one.

During the first sixteen years of our occupation of the Islands there was a continuous Republican regime in Washington, and during this period the

Islands were governed on an absolutely non-partisan basis. Men were chosen for their fitness or their experience and no consideration whatever was given to their party affiliations.

This condition continued until the Democratic regime came in, when President Wilson, or his representatives, called for the resignation of every member of the experienced Commission, Americans and Filipinos, except one Filipino. He replaced the tried Filipinos with new and inexperienced ones. He gave them a majority of the Commission, then the upper house of the legislature and filled the four remaining places on the Commission with new and inexperienced Americans.

Three out of four of these new appointees were what might be classed as "Deserving Democrats." A thin semblance of non-partisanship was observed by the appointment of one "Progressive." There was not a single man who had had previous experience in the Islands in this group of new administrators, nor did the President appoint to the Commission a single representative of the Republican party.

Prior to this, the personnel, which had presently rounded out into a thoroughly trained and admirable organization, was recruited largely from men who had gone out to the Philippines as volunteers and stayed out there because they liked it.

During the ten years that I was in the Islands I don't think I knew the political views of one person in ten of the hundreds of earnest and capable men with whom I worked.

I don't think it will be blowing one's horn too much to quote a summary of the government of the Islands made after a visit to the Orient by Professor Albert Bushnell Hart, Professor of Government at Harvard, and who is also a distinguished member of the Academy. He reported:

> ". . . the regime of the Philippine Islands is one of the marked successes of the American people. It stands high among the tropical colonial governments of Christendom, for the skill with which it was framed and the efficiency with which it was carried on; . . . it is not too much to say that no territory, no city and no state within the United States had a system of government so carefully thought out, so well concentrated and so harmonious in its parts as that of the Philippine Islands."

The American policy in the Philippines was neither to exploit the Filipinos in the interests of the home merchants nor of the Americans resident in the Islands.

The policy enunciated by Taft, "the Philippines for the Filipinos," was generally adhered to.

From the very beginning of the American occupation, the Filipinos were given the control of their municipalities. Early in the American regime they were further given the right to elect all the provincial officers. And within the first decade the legislative control was placed very largely in their hands by the creation of an elected lower house of the legislature. I have already told of President Wilson giving to the Filipinos the majority of the cabinet positions. Later the Commission, as such, was abolished and the Filipinos were given an elected senate.

In 1934 came the so-called Tydings-McDuffey act, under which a commonwealth under the sovereignty of the United States was created and under which the United States retains the power to intervene under certain and rather limited circumstances. The Filipinos now have an elected President who appoints his cabinet, their own supreme court with no requirement that any of the justices are to be American, and an elected legislature. The bill further provides that on the 4th of July, following the expiration of the ten year period, the Islands shall become absolutely independent.

Under the terms of the Treaty of Paris, by which the sovereignty of the Islands was ceded to the United States by Spain, it was stipulated that the Spaniards were to have tariff privileges in the Islands. Thus it was not until 1909 that the way was cleared for the passage of the so-called Payne Bill granting free trade between the United States and the Philippine Islands, with results that have already been shown.

Many Filipinos found their way to the United States and found employment there and were frequently seen holding service positions in our Navy. Rather looked down upon as a laborer, the Filipino disappointed his critics by proving to be an excellent workman.

The explanation for the failure of many Filipinos to show their value as laborers was not long in coming. Our sanitary officers found that the health conditions under which they lived were such as to sap their vitality. Most of them were found to be victims of debilitating intestinal parasites; and this was very largely remedied by the activity of our government in providing potable water, largely from artesian wells which were bored extensively throughout the Islands.

I have already told of the movement of Filipino laborers to Hawaii. There they proved their mettle in competition with labor from other countries, China, Japan, and also from Occidental countries such as Spain and Portugal.

The law under which they are now operating provides for a graduated tariff to begin at the expiration of five years from the date of acceptance of the law. One year from now the Philippines will begin to pay a duty of five per cent of what other countries pay on everything sent into the United States; the next, or second, year it will be ten per cent; the third, fifteen per cent; the fourth, twenty per cent; and on the final year before they get independence they will be paying twenty-five per cent, or one-quarter, of what other countries have to pay on similar goods brought into the United States.

This should not be enough to exclude very much of their produce, but it will give them a foretaste of the burdens that will ensue when the full duties are to be levied. Moreover, the United States has placed limitations already on sugar and coconut oil which may be admitted free into the United States.

The moment the United States relinquishes its sovereignty over the Islands, and they pass out from under our flag, the tariff between the United States and the Philippines will become subject to the Favored Nation clause in our treaties with many other countries. This would preclude our granting them preference in the admission of their goods. And if they were to pay full tariffs it would close our market to an important part of their produce and perhaps make it impossible for them to market their sugar to any great extent.

The Philippines are also on a quota basis in regard to immigration, the number being fifty per year according to the Tydings-McDuffy bill.

The United States has from the beginning of the Occupation proclaimed, both by resolutions of the Senate, and speeches of our presidents and high officials, that it has never been the intention of the United States to annex the Philippine Islands. And both parties have in their platforms held to the declared intention of giving the Filipinos their independence whenever a stable government should have been established. Whether or not the agencies that undertook to make these representations had the authority to bind the United States, there is no doubt that the Filipinos very generally believed that independence had been promised them, and if at any time the people of the United States should have decided to withhold it the Filipinos would have suffered an ominous disillusionment resulting in a strong feeling on their part that the United States had not kept faith with them. This might have created a situation which could have resulted in public disorder and possibly insurrection, which would have been very difficult to control. Moreover, under such circumstances there would inevitably be many Americans who would be inclined to sympathize with and aid the protesting Filipinos.

Personally, I feel that the United States has done the right thing in letting the Filipinos vote to determine their future status.

While it has often been convenient for certain of the Filipino leaders to make me out as an arch enemy of independence, I have never discouraged their desire for it; as that has always seemed to me an evidence of their proper self-respect. My hope has been, and still is, that the Filipinos would in the course of time see where their best interests lay and ask for a continuance of their present commonwealth status.

It has always been my belief that it would be most unfortunate if the Philippine Islands obtained a complete political separation from the United States. They are much safer under the American flag. They are much more prosperous with access to our markets. They had best continue under the relationship which exists today—a commonwealth in which the Filipinos have virtual control of their domestic affairs and in which the United States retains the power of intervention only under extraordinary circumstances. There is a growing sentiment among the Filipinos in favor of some such arrangement. Complete separation looks less alluring to them as the time for it gets nearer. Many of them feel that the present relationship is something they should hold to.

There is no doubt that the desire for independence has been steadily fomented by the politicians for vote-getting purposes, and as a popular slogan it has pretty well permeated the Filipino people. Their leaders, however, might very easily persuade them that a supervised commonwealth gives them as much independence as they really want, and that they now have sufficient direction of their own affairs to feel that they are in fact ruled by their own people.

From long association with the problem, I have reached the conclusion that it is unthinkable to annex the Philippines with the idea of their ultimately becoming a state, and I don't see how they could be annexed on any other basis. The Philippines might very easily grow to carry a population of fifty to eighty millions; they have enough territory and it is rich enough in resources to support a population of that size. It is unthinkable that such a group of people, with alien interests and points of view should be placed in a position where they could hold the balance of power between our parties in the halls of Congress in Washington.

Those who desire complete separation of the Philippine Islands from the United States may be placed in three groups:

First, there are those sentimentalists, often to be found in the ranks of the anti-imperialists, who want us to get out of the Islands and stay out. These are influenced in part by the Filipinos' desire for independence. And in this group are those who feel that we have no business to carry our sovereignty so far afield.

Secondly, there are those whose views are peculiarly economic, usually influenced by the effect of Philippine competition upon their own business; these have been led by a powerful and well-organized lobby subsidized by the sugar interests and have incidentally enlisted the support of those who have a real or fancied competition in tobacco, cordage or coconut oil. And among these are to be found lined up the farming interests which have, as many of us believe, been hoodwinked into the fallacious belief that the retention of the Philippines is injurious to their businesses.

The third group have a much more logical basis for their belief, which is that the possession of the Islands is a menace to our foreign relations with other countries; that it is a source of irritation and annoyance to the friendly nation of Japan; and they feel that this would be removed were we to step out of the Islands. These believe, and they are supported by competent officers of the army and navy, that the Islands are incapable of defense by the United States in case of war with a first rate power, which is undoubtedly true, and hence it is safer for us to get out and eliminate this weak spot in our defensive position. Other competent military officers, however, hold, as I do, that in case of war it would be waste motion to try to defend the Philippines, and similarly waste motion for our adversary to attack them. Blows should be struck at places vital from a military point of view, and the Philippine Islands are not vital to us and hence could not be a real source of weakness. Regardless of what happened to them in the course of war their final disposition would be settled in the council chamber when terms of peace are determined.

Let us study the strategic position of the Islands. In 1899 the German Chancellor, as revealed by German state papers, reported to the Emperor that he regarded the possession of the Philippines as the "key to the Pacific." It is certainly a depot at the gates of China.

When one remembers that our present trade with Oriental countries is only 14 per cent of our total foreign trade one can realize the importance of maintaining and controlling our trade routes.

In the early fifties a German, named Jagor, wrote the following interesting statement: "Only when the shores of the Pacific re-echo with the sounds of active commerce, will the trade of the world and the history of the world be said to have begun." Forward-looking Americans realize that it is important that we of the United States retain as far as possible every position of commercial advantage that we now hold. The waters of the Pacific should be kept free for our commerce.

Only recently we started a fortnightly trans-Pacific air service that carries mail and passengers, the latter resting each night on American soil, until they land in China.

I have discussed the continuance of American sovereignty in the Philippines with statesmen of many countries, especially those of Great Britain, and China, and also with men interested in commerce, and they all feel that the international equilibrium of the Orient will be much better preserved by the continuance of the United States' rule in the Philippines.

I am not proposing that we should reverse our policy and undertake to withdraw the grant of independence which has already been made to the Filipinos, I merely want to point out that in case it should seem wise to the Filipinos to ask for a continuance of their commonwealth status, that no mistaken theory of where our true interests lie should prevent the United States acceding to any reasonable request they might make.

POLICY

Now what is all this leading up to? It is clear that the United States can't undertake to fight the battles of any foreign peoples, whether we sympathize with their difficulties or favor their point of view, and it is clearly our duty when two foreign countries are at war, whether declared or not, to take no sides for or against either of the belligerents regardless of where our sympathies lie. No proposition to send troops abroad to fight other peoples' battles would secure a single supporting vote in Congress; and any administrative officer proposing it or taking it on himself to order such use of our troops or ships would seriously impair his prestige.

On the other hand, there are certain fundamental principles of national policy which should be declared and maintained, and for which we should fight if necessary and yet in the defense of which, if we are adequately prepared to fight, there is practically no chance of our being called upon to do so. Pusillanimous administrators putting forth words or threats, behind which there is no preparation for deeds, not only are likely to defeat their object, but they make us ridiculous in the eyes of the world and are quite likely to bring about the evils they are intended to avoid.

In this connection it is not a digression to tell two stories. One of them I got from the lips of Theodore Roosevelt, describing his action in regard to a proposed landing of German troops in Venezuela to enforce the settlement of a debt. The German Ambassador had called upon him, ostensibly about some other matter, and the President said to him: "By the way, speaking of the Venezuela matter, I hope the Kaiser will see his way clear to arrange its settlement by arbitration, because I am having the American Navy prepared for action. If arrangements are not made for its settlement within two weeks I shall send Admiral Dewey down there with instructions to prevent the landing of the German troops, by force if necessary." The German Ambassador, visibly disturbed, said: "This means — I don't like to use the word." "I don't mind saying it," said Theodore Roosevelt. "It means WAR." The Ambassador went off and two or three days later came back again and the President, after talking of other matters, said: "By the way, Mr. Ambassador, I have been thinking that Venezuela matter over and I have decided two weeks is rather too long to wait. The Navy is more nearly ready than I thought and if your Emperor hasn't decided to settle the matter by arbitration, I shall direct Admiral Dewey to go down at the end of one week." Germany was not at all prepared to make war against the United States overseas; the matter was settled by arbitration; the American Navy was not called upon to go down, and there was no war, as Theodore Roosevelt knew very well there would not be.

The other story is of two soldiers, one of whom was extolling the achievements of President Wilson in the World War: four million men under arms, two million men overseas, so many billions of dollars spent, so many millions of tons of munitions, of supplies, of tonnage of ships sent across, etc., etc. The other one listened, and said: "Yes, Woodrow Wilson achieved all this; I give him full credit; but Theodore Roosevelt would have accomplished just exactly as much and the only output would have been the display of two sets of teeth."

The application of all this to the Oriental situation is that we can expect the Japanese to go just as far in crowding as she thinks other nations will let her go without taking action. I should like to contrast for a moment the course pursued by the Russians with that pursued by our State Department in 1930, 1931, and 1932. The Russians began by asking the Japanese to join them in a non-aggression pact. This the Japanese declined to do. The Russians then made no more replies, sent no notes; but started moving vast quantities of munitions, artillery, the material and supplies necessary for the conduct of an extensive campaign, and a body of some 100,000 troops, which they massed on the Manchurian frontier. There has been no resulting war between Japan and Russia, but the Russians have spoken without words in a language which the Oriental mind thoroughly understands.

I heartily approve of the course taken by our present administration in regard to our Oriental problem. They have not sent sheaves of notes; there have been very few representations made to the Japanese. On the other hand, we have set out to build up our navy to treaty strength.

Until very recently, it has been a matter of treaty, settled in Washington in 1922, and later reaffirmed in London, that the United States, Great Britain, and Japan should maintain navies with the ratio of ten for the United States and Great Britain and six for Japan. The Japanese army clique have cleverly utilized this arrangement to make their people feel that the ratio of 10, 10 and 6 was a measure of inferiority of the Japanese people, and, harping on this theme, they demanded parity as indicating what they regard as comparative importance. This feeling had become so strong that any party or group that assented to anything less could not safely return from a treaty conference to Japan. They do not seem to realize that the United States has two frontiers on two oceans to defend, nor that Great Britain has a far flung range of possessions.

There was only one thing for our administration to do and that was merely to inform the Japanese government that we propose to build ten ships for every six that they have.

If they start an armanent race it will inevitably spell ruin for their exchequer, as we have vastly greater resources than they, despite their lower costs.

On the other hand, until we have ten ships to their six, it will be futile for us to suggest to them any reduction in armanent. Imagine the position in which our negotiators would find themselves if instead of a ratio of ten to six we allowed our navy to drop to seven to their six, and then undertook to tell them that while we held our navy at seven they must reduce theirs to 4.2.

When our navy has been built up to the required strength, namely: ten for every six ships they have, our negotiators could then say: "Come, let us reduce our navies and save expense. We will destroy ten ships for every six you put out of commission." If the Americans and British were to join forces in the defense of their Oriental interests and possessions, as they should, we would then be in a position to say to Japan: "We and Great Britain will destroy twenty ships for every six you put out of commission."

After this reduction had been completed, the numerical ratio of our fleets would remain the same but the advantage would be general and the arguments in favor of this course might be very appealing to countries that are finding it difficult to balance their budgets.

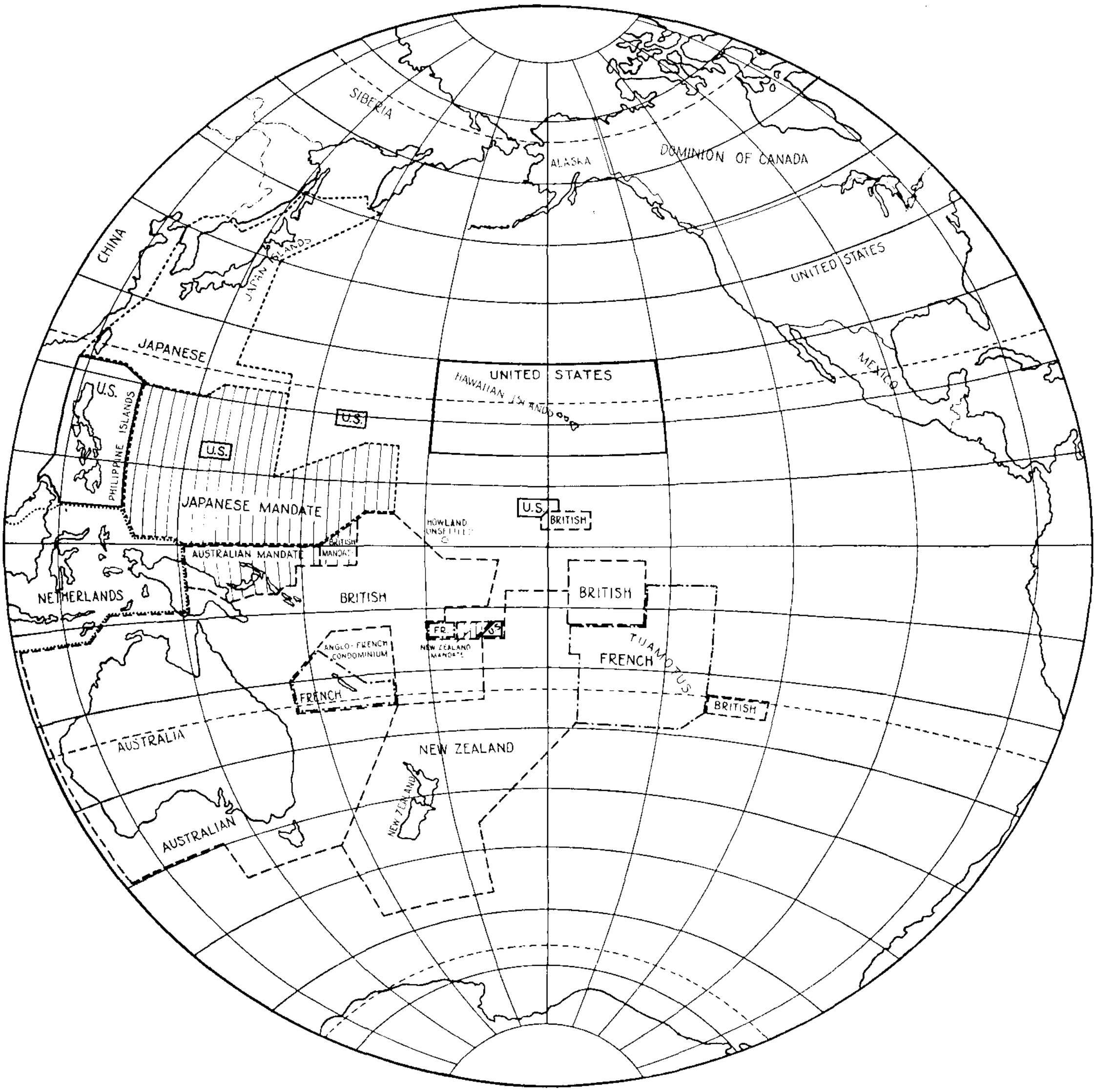
Protection of investments abroad has been given the unpleasant name of "Dollar Diplomacy" and yet in the long run we would keep ourselves out of more trouble and out of greater international complications if the world knew that the United States stood ready to protect the property as well as the persons of its nationals.

Our dignity and prestige in foreign courts and chanceries should be preserved at all costs. One does not have to go farther back than the period when William Jennings Bryan was Secretary of State, to learn of humiliating instances where Americans had to seek the assistance of British diplomatic representatives to secure the protection which our own representatives, under instructions of their government, were unwilling to give.

Our country has been too self-contained to have any realizing sense of the importance of investments beyond our borders. Unlike Great Britain and Japan, where the small confines of their homelands make them look eagerly to other regions, we are too introspective but the time will come when we shall more and more send our sons abroad to develop and extend our connections; and when that time comes our people will awaken, perhaps too late, to a realizing sense that foreign climes, foreign trade, and foreign outlays and proper protection to our citizens and their interests when outside our borders are just as important an item of national policy as looking after their interests when at home.

I hope some day the United States will enunciate the following three cardinal principles:

1. The United States will protect, by force if necessary, her ships, citizens and their property wherever situated.
2. The United States will tolerate no interference with the right of American shipping to traverse the open seas.
3. It does not comport with the dignity of the United States to have a third party dictate our relations, whether economic or political, with any friendly country in the world.


SIBERIA
ALASKA
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MEXICO
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PHILIPPINE ISLANDS
U.S.
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JAPANESE MANDATE
U.S.
BRITISH
HOWLAND UNSETTLED
BRITISH MANDATE
AUSTRALIAN MANDATE
NETHERLANDS
BRITISH
BRITISH
FR.
NEW ZEALAND MANDATE
ANGLO-FRENCH CONDOMINIUM
TUAMOTUS
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FIGURE 1. The Pacific Ocean showing boundaries of the spheres of influence of various nationalities.

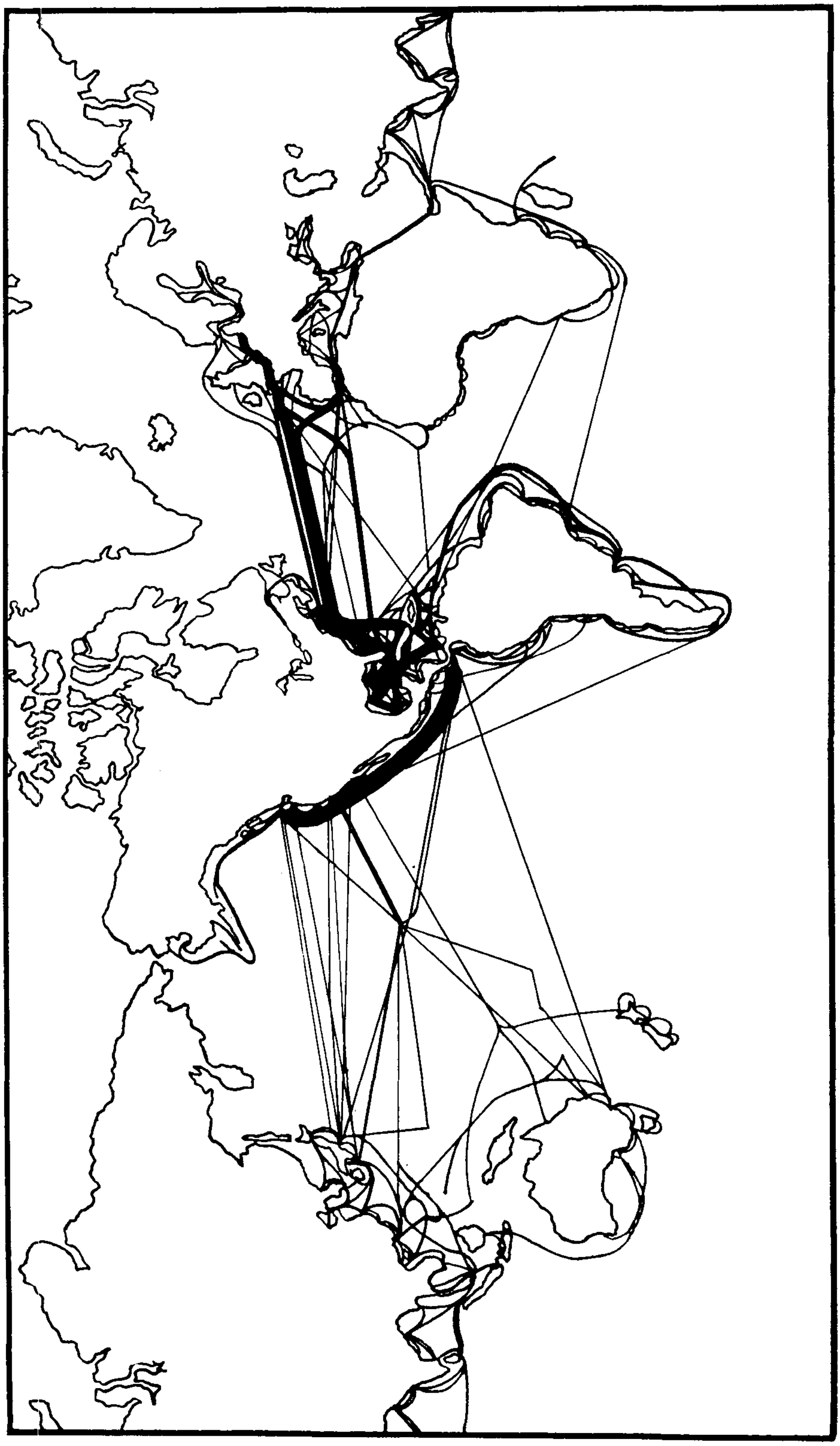
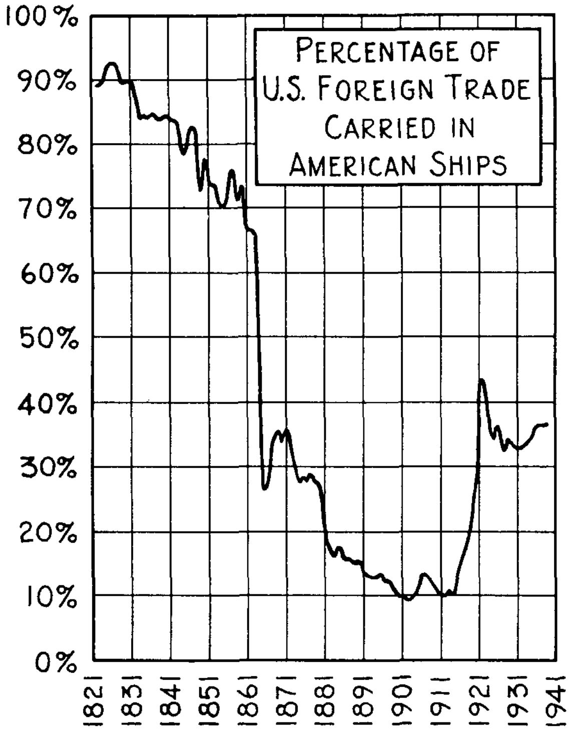


Figure 2. United States commercial steamship lines. The width of each lane is proportional to the number of lines using it.



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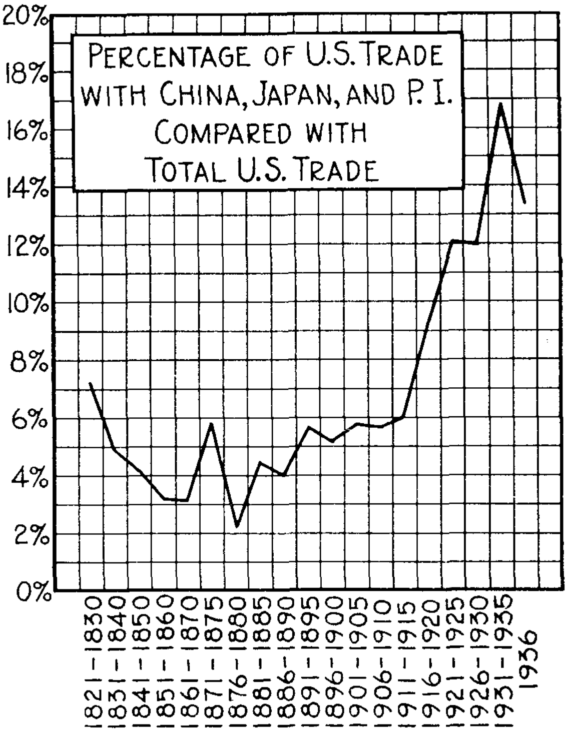

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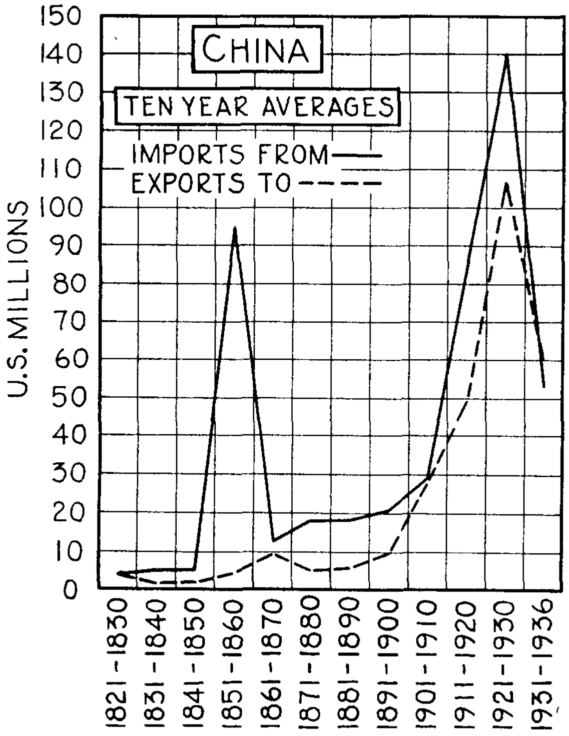

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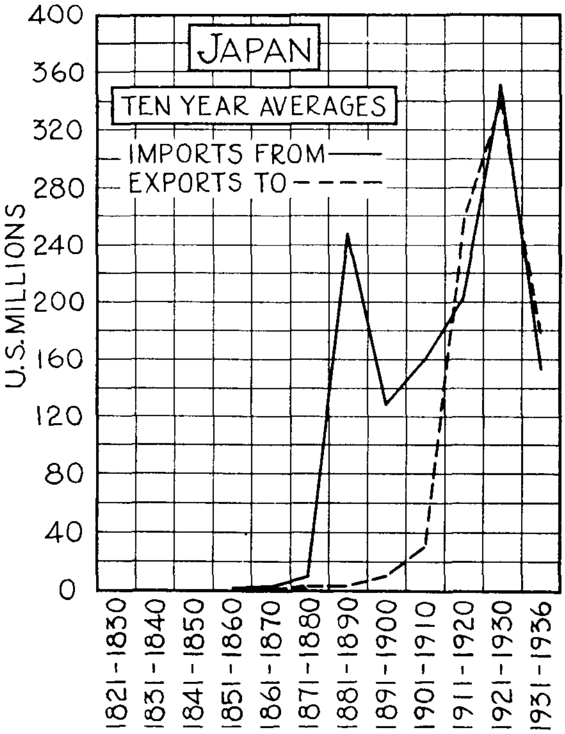

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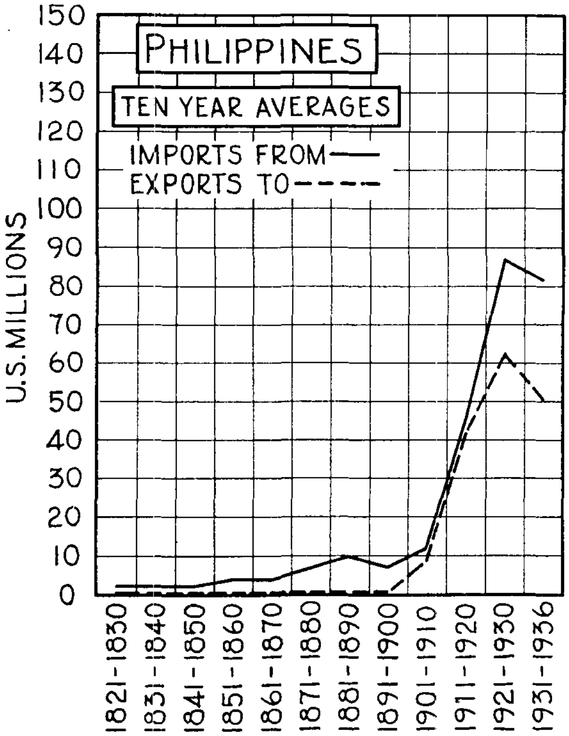

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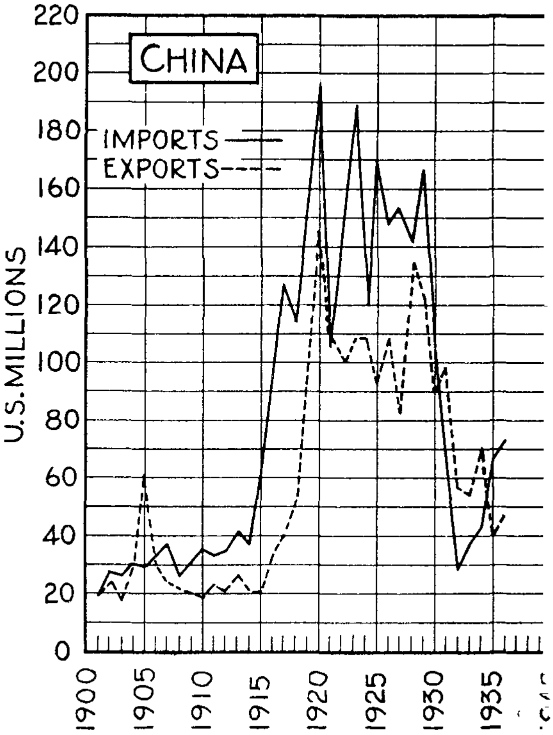

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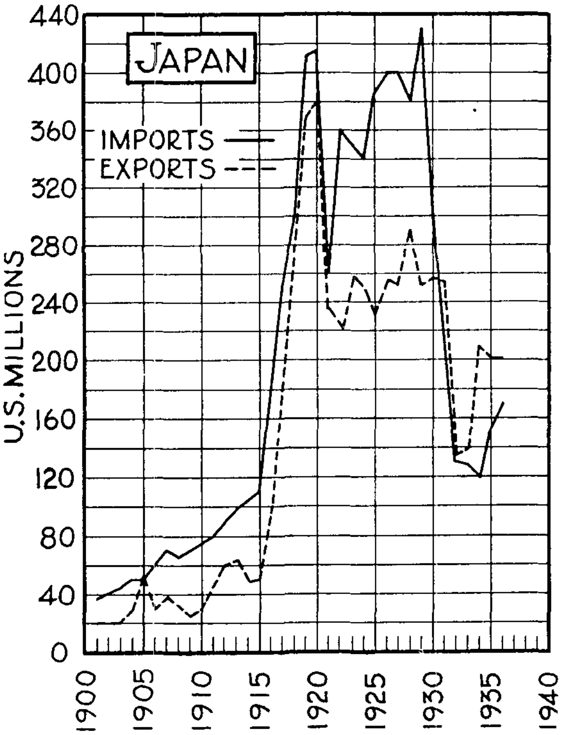

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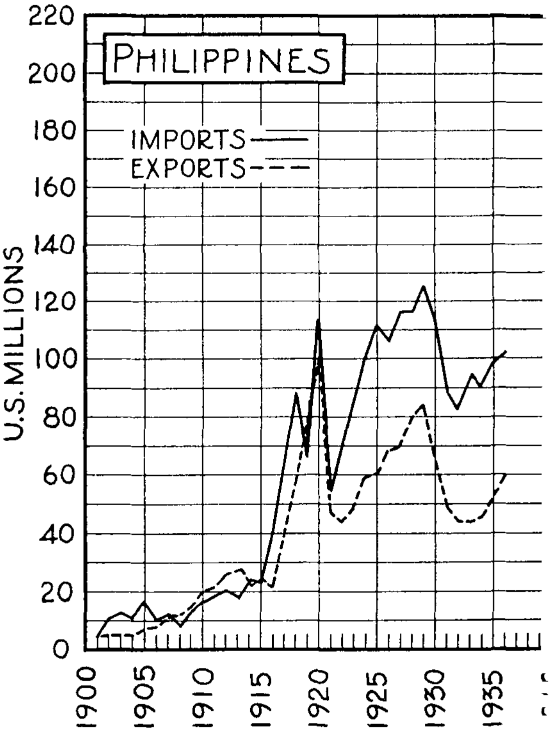

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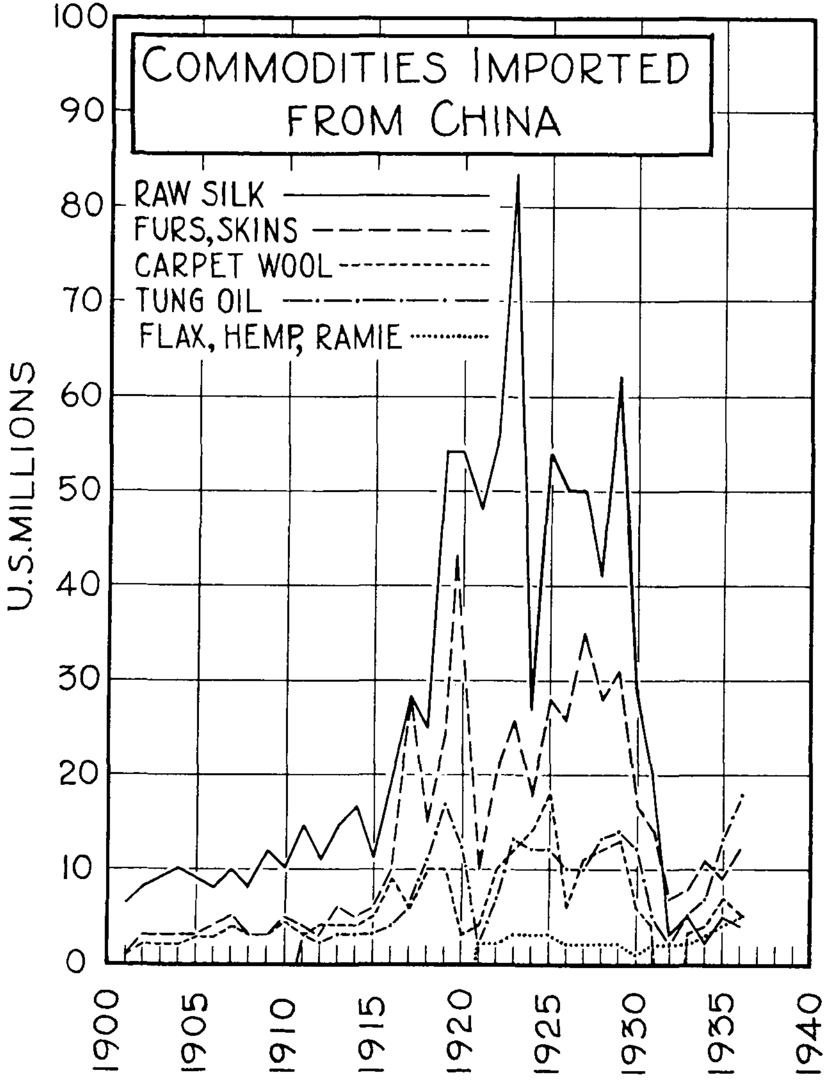

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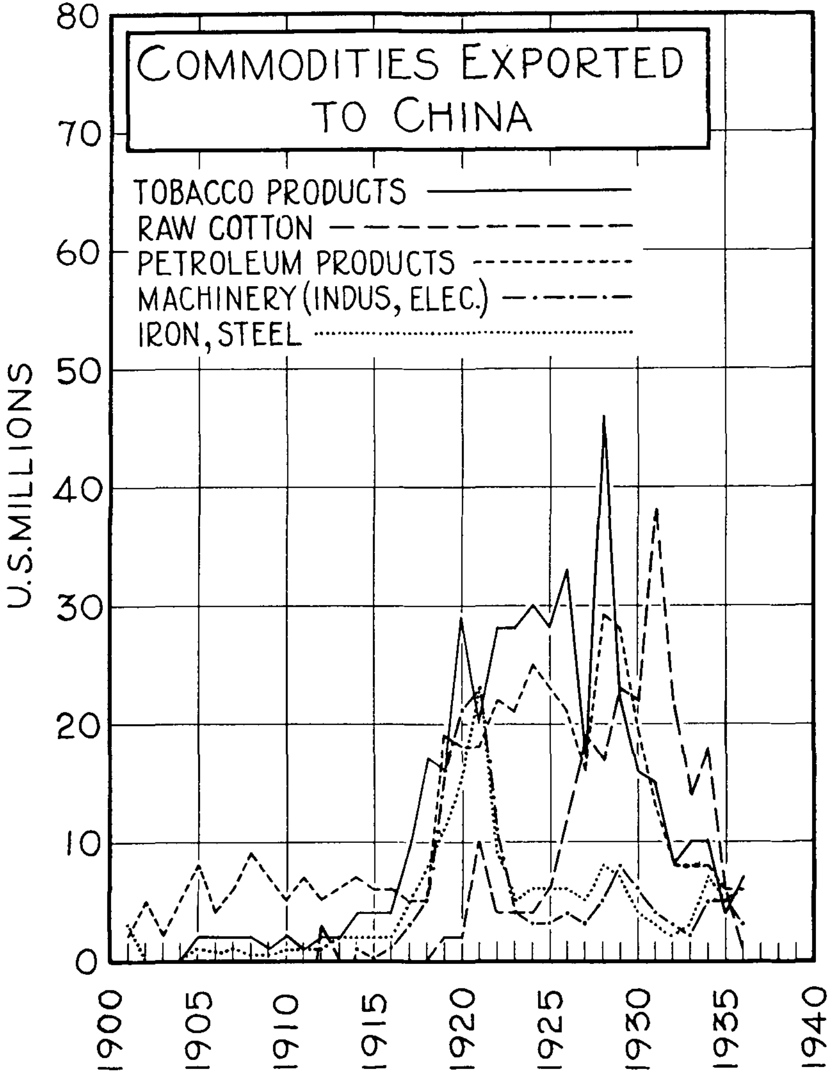

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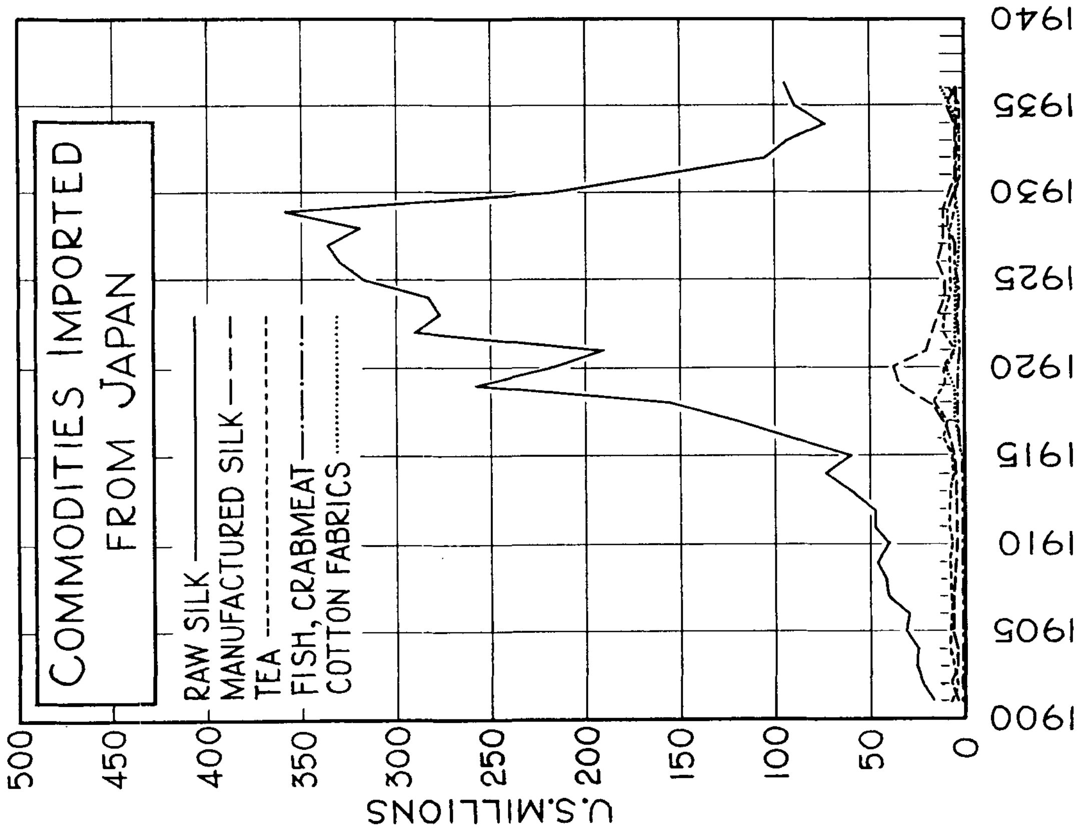

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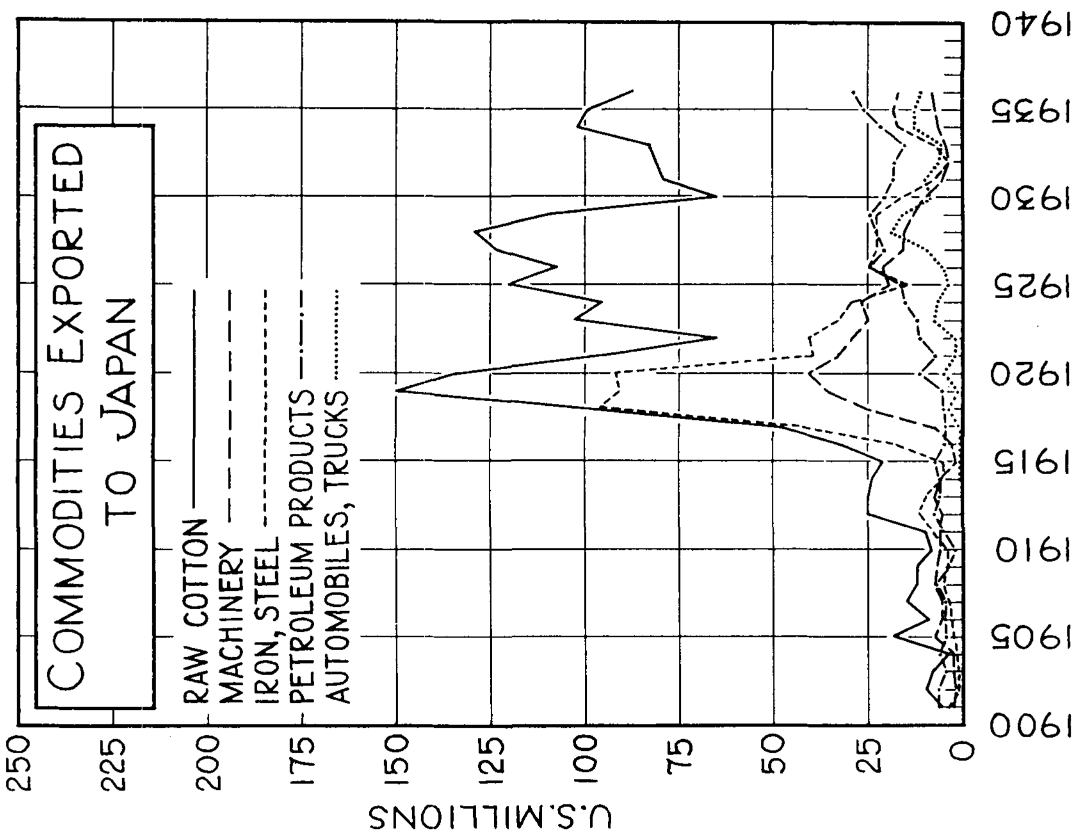

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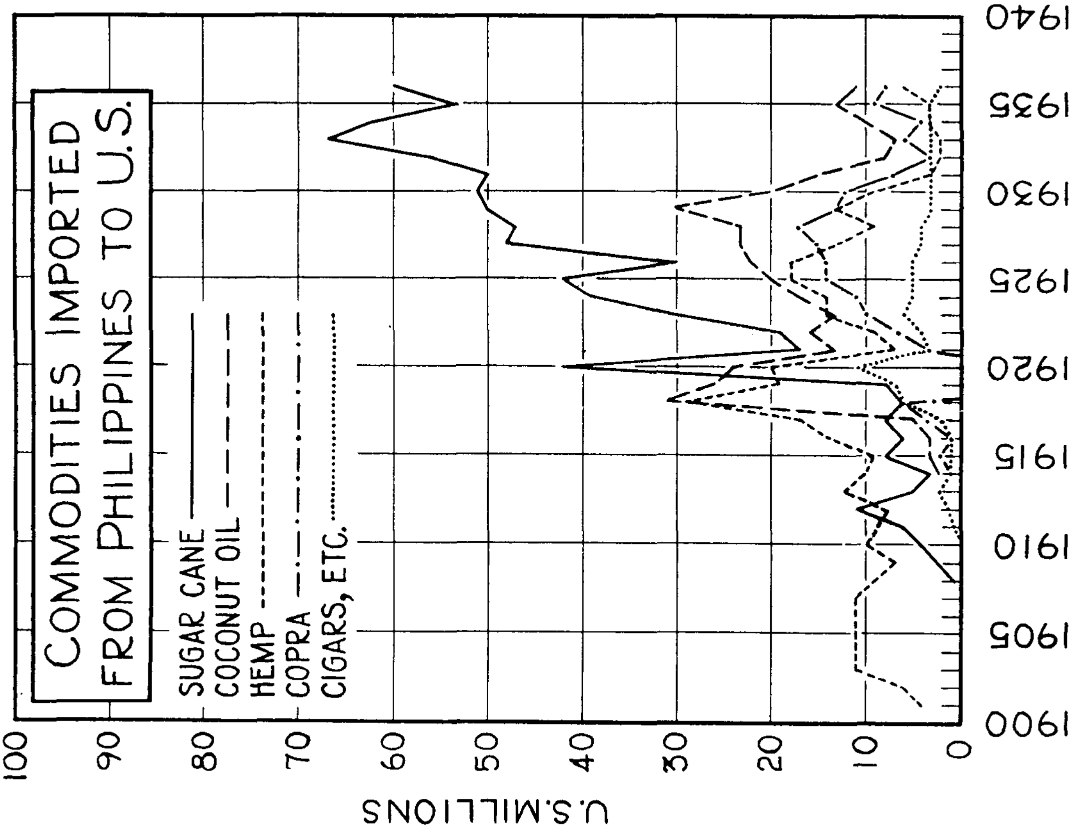

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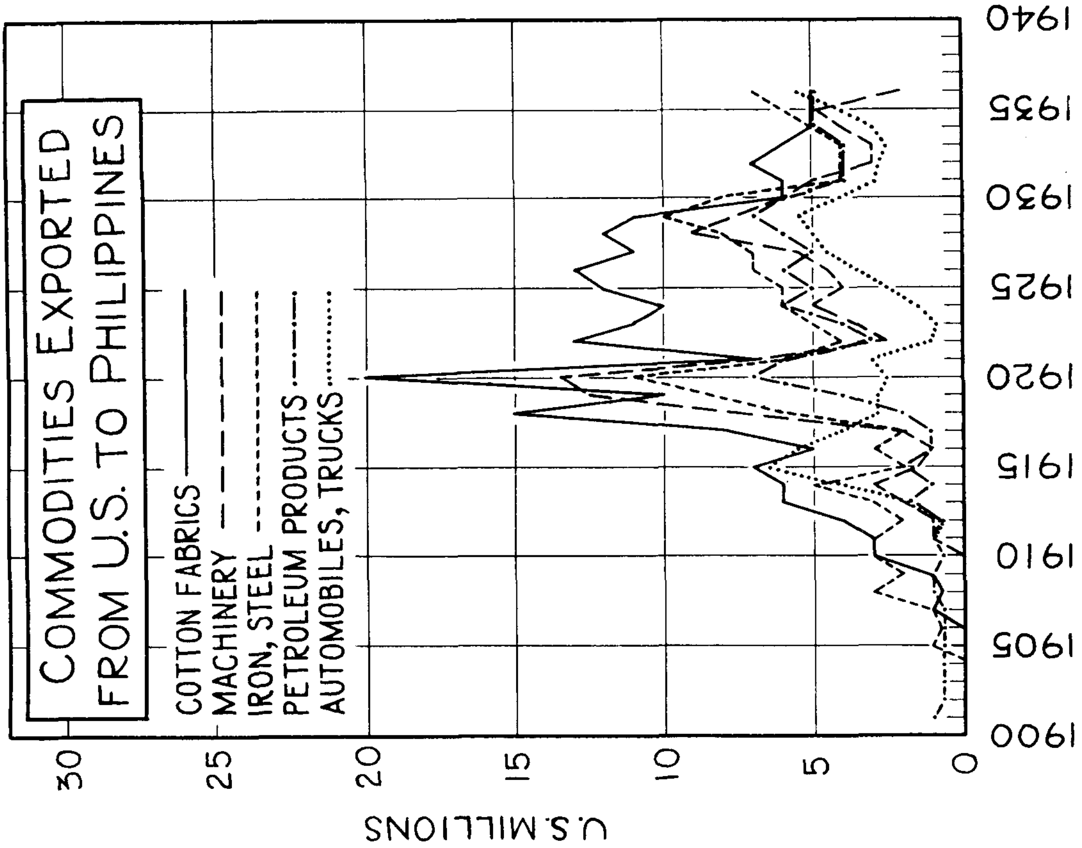

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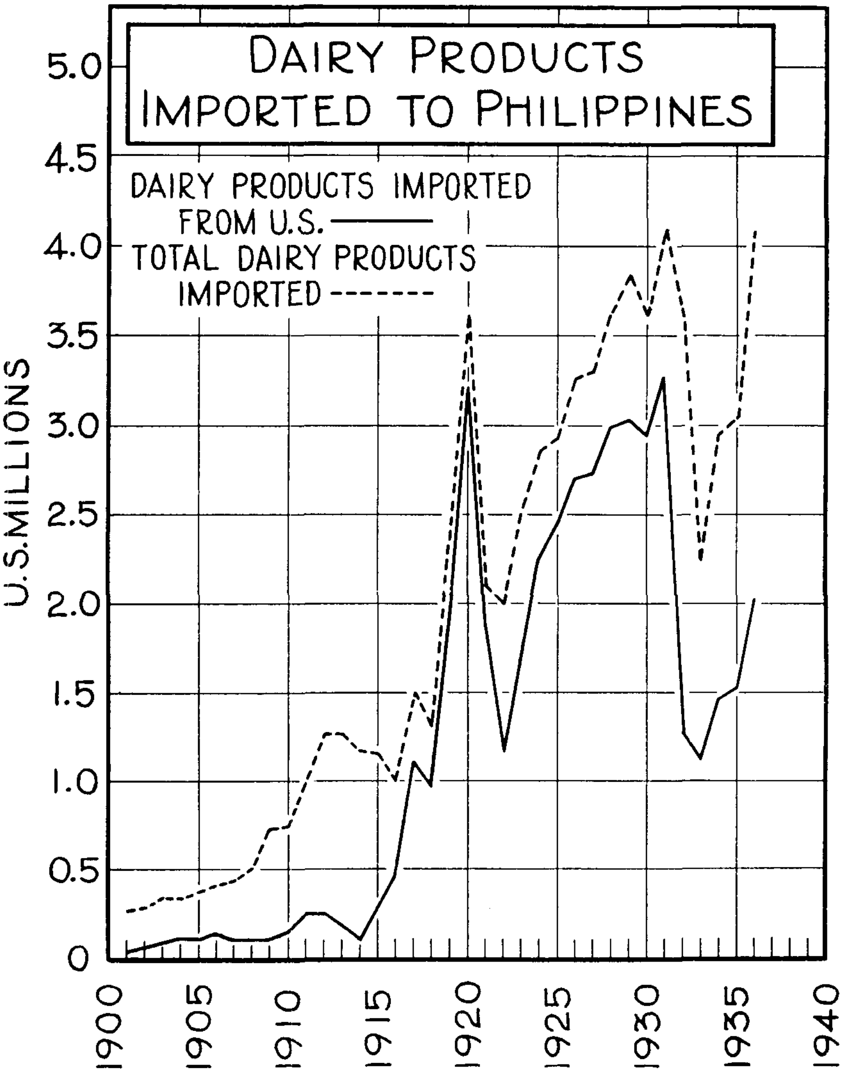
DAIRY PRODUCTS
IMPORTED TO PHILIPPINES
DAIRY PRODUCTS IMPORTED
FROM U.S. ————
TOTAL DAIRY PRODUCTS
IMPORTED -------
U.S. MILLIONS
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
1900
1905
1910
1915
1920
1925
1930
1935
1940

FIGURE 17.

THE LOWER PERMIAN INSECTS OF KANSAS. PART 8

ADDITIONAL MEGASECOPTERA, PROTODONATA, ODONATA, HOMOPTERA, PSOCOPTERA, PROTELYTROPTERA, PLECTOPTERA, AND PROTOPERLARIA

BY FRANK M. CARPENTER

Received February 15, 1938 Presented March 9, 1938

In the summer and fall of 1935, a few months after the previous part of this series of papers was published, the writer made another trip to the Lower Permian limestone at Elmo, Kansas, and secured several thousand more insects for the Museum of Comparative Zoölogy. The Museum collection from this formation now exceeds eight thousand specimens.

The new fossils were found in the same quarry which yielded the 1932 material. At this quarry, as I have previously indicated (1933, p. 411; pl. 1, fig. 1), the insect-bearing limestone occurs in two layers, separated by a thin bed of soft calcareous shale. The new collection therefore includes specimens from both layers, though the majority of them were found in the upper one. The quarry was worked eastward, i. e., in the direction in which the photograph already mentioned was taken. At a distance of about 15 feet from the front of the quarry a noticeable decrease in the thickness of the limestone was apparent. This diminution took place in both layers and became more pronounced as the quarry was developed further eastward, so that at a distance of about twenty feet from the starting point, the limestone was entirely absent (Plate 1, fig. 1). I have previously called attention to the apparent lenticular mature of the Elmo limestone (1933, p. 412), but this new exposure is the first one actually to reveal the edge of one of the beds. It should be noted that as the limestone thins it becomes less fossiliferous. Most of the new fossils were collected at the west end of the quarry, where both layers were very thick.

This paper deals only with those specimens contained in the 1935 collection belonging to the orders and families which I have already treated in earlier publications, namely, the Megasecoptera, Protodonata, Odonata, Homoptera, Psocoptera, Protelytroptera, Plectoptera, and Protoperlaria. There is, of course, a great deal of duplication of the species previously collected, but the new fossils add materially to our knowledge of their structure. In some instances the additional information has made it necessary to revise our opinions of their classification and affinities. This latest collecting trip was in fact made, not with the expectation of securing many new species, but with the hope that a large series of additional fossils would show structural details formerly unknown in the species which had been found, especially of the Protohymenoptera, Odonata, and Homoptera. In this respect the results of the trip were very satisfactory, for the 1935 collection exceeds all others in the number of complete or nearly complete specimens included.

Before closing these introductory remarks, I wish to acknowledge the financial aid of two grants which made the 1935 trip possible; these were obtained from the Permanent Science Fund of the American Academy of Arts and Sciences and the Penrose Bequest of the Geological Society of America. I also acknowledge the invaluable assistance of my wife, who accompanied me on the trip and found a large proportion of the new fossils. As on former occasions we are indebted to Mr. and Mrs. E. E. Bert and Miss Rowena Bert for their kindness during our stay in Abilene; and to Paul and Joseph Bert for their assistance in the field.

Order MEGASECOPTERA

Suborder Protohymenoptera

Some of the most interesting fossils collected in 1935 are members of the group which Tillyard has termed the Protohymenoptera. Sixty-one new specimens of these insects were found, making a total of 143 in the Museum of Comparative Zoölogy. Forty-one of the new fossils were secured in the upper layer of the limestone, and twenty in the lower layer.

Family PROTOHYMENIDAE

Genus *Protohymen* Till.

Protohymen Tillyard, 1924, Amer. Journ. Sci., (5) 8: 113.

Protohymen Carpenter, 1930, Psyche, 37: 349.

In addition to the new species described below there are three species in the new material belonging to this genus. *Protohymen permianus* Till. is represented by four specimens, consisting entirely of single wings; two of these (Nos. 3807ab and 3809ab) were found in the upper layer, and the other two (Nos. 3808ab, 3810ab) in the lower. One specimen (No. 3811ab), consisting of the apical third of a wing and belonging to *Protohymen readi* Carp., was found in the upper layer. *Protohymen elongatus* Carp. is represented by two fossils from the upper layer (Nos. 3813ab, and 3814ab), the former being the best specimen of the wing which has yet been found. It has a venation like that of the holotype except that there are two cross-veins instead of one between 1A and the hind margin.

Protohymen tenuis, new species

Figure 1

Fore wing: length, 12 mm.; width, 2 mm.; very slender, the anterior margin not so strongly curved as in other species of the genus; R1 contiguous with the costal margin for its whole length; no cross-vein between R1 and Rs proximal of the pterostigma; the one cross-vein between Rs and MA is distal of the fork of Rs; Cu1 coalescing with the stem of M, as in other species of the family; MP separating from Cu1 at a point remote from the base of the wing, well distad of the first cross-vein between Cu1 and Cu2; 3 cross-veins between Cu1 and Cu2, but only 2 between Cu2 and 1A; 1A much shorter than in other species of *Protohymen* except *permianus*.

Hind wing unknown.

Holotype: No. 3812ab, Museum of Comparative Zoölogy; collected by the writer in the lower layer of limestone at Elmo in 1935.

This wing is the most tenuous of all the known Protohymenoptera. In many venational features, as well as in shape, the wing approaches that of *elongatus;* but it is so much smaller than *elongatus* (which is 19 mm. long) and possesses such a distinctly shorter 1A that I am convinced it represents a distinct species.

Genus *Permohymen* Till.

Permohymen schucherti Till.

Figure 2A

Permohymen schucherti Tillyard, 1924, Amer. Journ. Sci., (5) 8: 116.

Permohymen schucherti Carpenter, 1936, Psyche, 37: 354.

Five specimens of this species were found in 1934. Three of these (No. 3816, lower layer; No. 3817, upper layer; No. 3818, lower layer) consist of wings only, but the other two show various parts of the body. Since nothing has previously been known about the body structure of *Permohymen,* the latter specimens are of particular interest. One of them (No. 3815ab, upper layer) shows the abdomen and part of the thorax in lateral view, as well as one complete wing; this specimen has an ovipositor, much like that already described in *Asthenohymen* (Carpenter, 1932), although the details of the various parts cannot be distinguished. The presence of the ovipositor in *schucherti* has much significance, since it demonstrates that *Asthenohymen* was not the only genus of the Protohymenoptera to possess this structure. In all probability an ovipositor also existed in *Protohymen.*

The other specimen of *Permohymen schucherti* (No. 3819ab, upper layer) is of even more interest, since it consists of almost the whole insect, although the legs, cerci and details of the head are not preserved. The dimensions of this specimen are as follows: length of entire body, 8 mm.; head, 1 mm. long, 1.5 mm. wide; thorax, 3 mm. long, 2.5 mm. wide; abdomen, 4 mm. long, 2 mm. wide. Since the wing is 10 mm. long, the abdomen is proportionally much shorter than in *Asthenohymen.* The most striking feature of this specimen is the genitalia, which are obviously those of a male. They consist of a pair of large claspers about 2 mm. long and a pair of much smaller processes nearer the median axis of the abdomen (Figure 2A). These genital structures are strikingly similar to those of the existing may-flies (Figure 2B), the two claspers obviously being the homologues of the styli of the may-flies. Like the latter structures the claspers in *Protohymen* are apparently "jointed" near the middle, though they lack the distal false-segments of plectopterous styli. The distal piece of each of the claspers bears distinct impressions of blunt teeth or tubercles along the inner margin. The two inner processes are apparently the homologues of the paired penes of the may-flies; at any rate no other interpretation of them has occurred to me. The presence of paired penes in *Protohymen* is especially interesting, for the only Recent insects with such structures are the Plectoptera and some Dermaptera.[1] The significance of the

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[1] According to Snodgrass (1936) the lateral gonoducts of the male have separate openings, perhaps second-

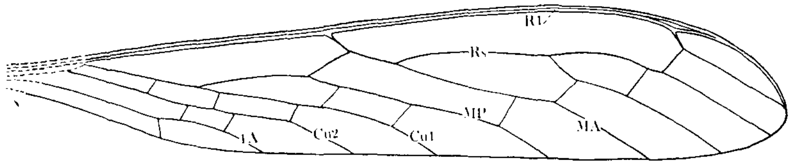

FIGURE 1. *Protohymen tenuis*, n. sp., drawing of fore wing; holotype, No. 3812ab, Museum of Comparative Zoölogy.

paired penes in these two orders is uncertain. Snodgrass is of the opinion that there is no specific evidence of the production of a median intromittent organ by the union of paired penes in any insects other than the Dermaptera and Plectoptera, and that in these two orders a union of the penes has taken place quite independently. The presence of the paired penes in *Protohymen* may not, therefore, have any phylogenetic significance, but it does suggest a relationship between the Protohymenoptera and the Plectopteran ancestors.[2] This is quite in accordance with the view that the Protohymenoptera are megasecopterous, since the Plectoptera have been generally regarded as part of the complex which also consists of the Odonata, Megasecoptera, and Protodonata.

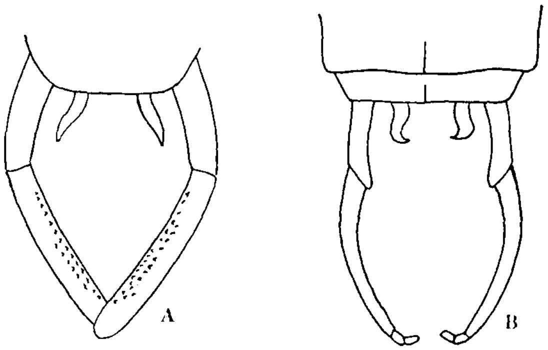

FIGURE 2. A. *Permohymen schucherti* Till., drawing of male genitalia; specimen No. 3819ab, Museum of Comparative Zoology. B. *Hexagenia* sp. (Recent, Plectoptera), drawing of male genitalia.

This same specimen of *Permohymen schucherti* (No. 3819ab) also shows small lateral processes on several of the abdominal segments. These may be vestiges of gills, similar to those which occur in the Palaeodicyoptera and Protoperlaria, but I think it more probable that they are only flaring lateral margins like those of some existing mayflies (*e. g., Siphlonisca aerodromia*).

Family ASTHENOHYMENIDAE

Genus *Asthenohymen* Till.

Forty-seven specimens of species belonging to this genus were collected in 1935. Most of these belong to *dunbari* or *pusillus*, but one excellent wing is referable to *affinis*.

Asthenohymen dunbari Till.

Figure 3

Asthenohymen dunbari Tillyard, 1924, Amer. Journ. Sci., (5) 8: 117.

Doter minor Carpenter (nec Sellards), 1930, Psyche, 37: 360.

Thirty-two specimens were found in 1935, eleven from the lower layer, the rest from the upper layer. Four of these specimens are of much interest since they present enough of the body structure to enable us for the first time to make a complete reconstruction of the insect and to determine the differences between the fore and hind wings. Specimen No. 3821ab (lower layer) is a lateral view of the whole insect and shows the head particularly well. No. 3820 (upper layer) is also a lateral view of the whole specimen, the head and ovipositor being well preserved. No. 3822ab (lower layer) shows an oblique view of head, but a lateral view of the rest of the body; the cerci are complete and are 12 mm. long. No. 3823ab (lower layer) is a dorsal view of a whole specimen, showing especially well the habitus of the insect.

In previous papers (1930, 1931) I have already described the legs, antennae, and the terminal part of the female abdomen, including the ovipositor. With the addition of the new material, it is now possible to give a fairly complete account of the body structure of this insect. The body as

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arily, in certain Diptera. The Protura also have separate openings, but these arthropods are not consistently regarded as insects, and their bifid organ is apparently not homologous with the penes of insects.

[2] It is pertinent to note that the male genitalia of the Permian may-flies (Permoplectoptera) are very similar to those of the Recent ones, although the penes of the Permian species have not yet been seen.

a whole was slender, and the abdomen was nearly as long as the wings, so that when the insect was at rest, with the wings folded back over the body, the abdomen proper projected slightly beyond the wing tips. The antennae were about two-thirds as long as the wings (3.5 mm. in specimen No. 3115ab), and contained almost 35 segments, the two proximal ones being much larger than the others (No. 3115ab, 3823). The head, seen from above, was rounded, with prominent but apparently not bulging eyes. The most extraordinary feature of the head has only now been brought to light by the new specimens: the prolongation of the head into a rostrum, resembling that of *Panorpa* (Mecoptera). This beak is not, of course, visible in specimens showing dorsal or ventral views of the insect; it can be distinguished only in those preserved in a lateral position. Fortunately three specimens in lateral view were secured in 1935 and in each of these the beak is very distinct (Nos. 3821ab, 3820ab, 3822ab). The lateral specimen which I described and figured in 1931 (p. 127, fig. 7) also shows this beak; but the appearance given by this specimen was that part of an antenna was resting across the head in such a way as to give the impression of a rostrum. The clear preservation of a beak in three additional specimens, however, eliminates such a misinterpretation of the head structure. In specimens No. 3821ab and No. 3820ab the head and rostrum together are 1.8 mm. long; in No. 3822ab, which is a little smaller, they are 1.5 mm. long (Plate 2, fig. 2). It is not possible to identify the various mouth-parts in these specimens, and it is very probable that we shall never be able to make out these details in such small insects; but that the mouth-parts were mandibulate is hardly to be questioned. The thorax was about three times as long as the head, as seen from above, the prothorax being the smallest part (.7 mm. long in Nos. 3821ab, 3823ab). The meso- and metathoracic segments were about equal in length (1.2 mm. in No. 3821ab) and distinctly broader than the head. The legs are well preserved in a number of specimens but are particularly clear in specimens Nos. 3115ab, and 3059ab. The fore legs (length, 2 mm. in No. 3115ab) were shorter than the others; the fore femur was shorter but stouter than the tibia, and the tarsus consisted of three subequal segments. The middle legs were slightly larger than the fore pair (2.5 mm. in No. 3115ab and 3059ab), and the third tarsal segment was about twice as long as the others. The hind legs were the longest of all (3 mm. in 3059ab), and had the tarsal structure like that of the middle pair. Small tarsal claws were present but further details of the pretarsus are not discernible. The abdomen of the female shows 11 segments visible from above; the segmentation of the abdomen has already been discussed with reference to the ovipositor (Carpenter, 1931, p. 128), and one of the 1935 specimens (No. 3823ab) bears out the earlier conclusions. The ovipositor itself is best preserved in the specimen (No. 3059ab) in which it was originally described; and it shows in lateral view in only one other specimen (No. 3820ab). Its greatest length (*i. e.*, ventral valve) is 3 mm., and it protrudes very slightly beyond the end of the 11th abdominal segment. In this connection specimen No. 3823, which is a dorsal (or ventral) view of the insect, is particularly interesting. The cerci are somewhat separated proximally in this fossil, and between the first two segments a median process is discernible. The nature of this process becomes clear when the specimen is examined under the binocular microscope with the light directed from one side of the insect; this arrangement shows very clearly the outlines of the whole ovipositor and demonstrates that this median process is the tip of the ventral valve. This is the only specimen which has thus far been found that shows the ovipositor in a dorsal-ventral view. Nothing is known so far of the male genitalia of *A. dunbari* or for that matter of any of the Asthenohymenidae. The cerci are exceedingly long in *dunbari;* their full length being 12 mm. (No. 3822ab, plate 2, fig. 2), which is about twice as long as the entire body. They contain about 88 segments, each of which bears a pair of hairs directed distally.[3]

So far as the wings are concerned, it is now clear from the complete specimens secured in 1935 that the hind wings were very similar to the fore, differing in minor details only. As I suggested in 1933 (p. 429) the supposed variation in the shape of the individual wings is a matter of the differences between the fore and hind pair. The fore wing has a slightly bulging costal margin near the base and a smoothly curved anal margin, whereas the hind wing has a straight costal margin

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[3] It should be noted that specimen No. 3822ab, which shows the complete cerci, is slightly smaller than specimen No. 3115ab, in which the cerci were originally described. This accounts for the fact that although the cerci of the former are only about 2 mm. longer than those of the latter, they contain 1/3 again as many segments.

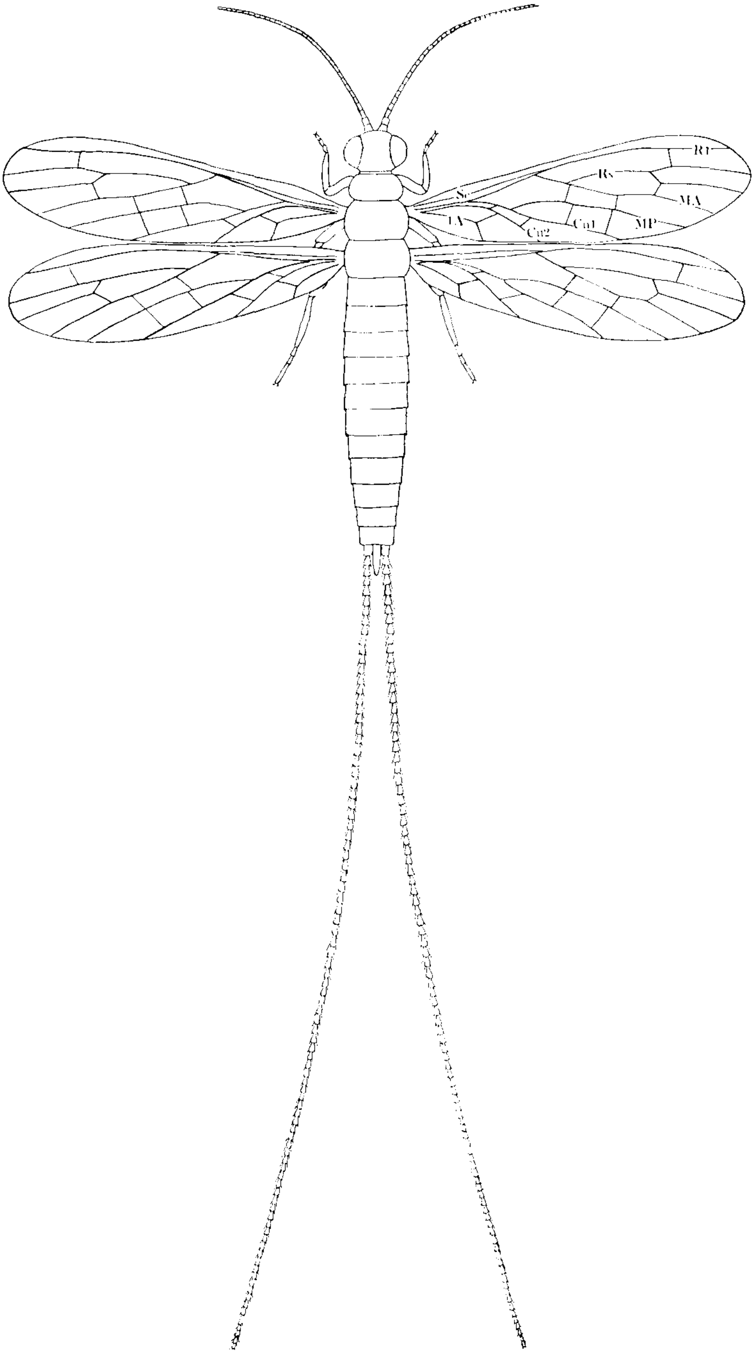

Figure 3. *Asthenohymen dunbari* Till., reconstruction, based mainly on specimens numbered 3820ab, 3821ab, 3822ab and 3823ab in the Museum of Comparative Zoölogy.

proximally and a more angular anal margin. In connection with the latter characteristic the first anal vein (1A) is somewhat shorter in the hind wing than it is in the fore.

Asthenohymen pusillus Till.

Asthenohymen pusillus Tillyard, 1926, (5) 11: 68.

Twelve specimens of this species were collected in 1935, all but one coming from the upper layer. Four of them (Nos. 3834, 3836, 3825, 3839) are especially fine wings. The differences in the fore and hind wing now known in *A. dunbari* show that the specimen of *pusillus* figured by me in 1933 (fig. 7) is a hind wing.

THE AFFINITIES OF THE PROTOHYMENOPTERA

In my first account of the Protohymenoptera (1930) I concluded from the available evidence that (1) the venation of the Protohymenoptera was incorrectly interpreted by Tillyard; (2) the Protohymenoptera were closely related to the Megasecoptera and not more than a suborder of that group; and (3) the Protohymenoptera were not ancestral to the Hymenoptera, as originally claimed by Tillyard. Although Tillyard has briefly expressed his opposition to these views (1932), it is only very recently (1936) that he has discussed the subject in detail. In this latest account he accepts the interpretation of the venation of the Protohymenoptera which I proposed in 1930 and he furthermore accepts the idea that the Protohymenoptera are very closely related to the Megasecoptera. He prefers not to regard the Protohymenoptera as a suborder of the Megasecoptera, though he states (1936, p. 450) that it is a matter of personal choice whether the group is regarded as holding subordinal or ordinal rank. He therefore admits the validity of the first and second of my conclusions regarding the Protohymenoptera, but refuses to concede that the third conclusion is correct, and in fact advances additional arguments to support his original view.

As I pointed out in 1930, in demonstrating that the Protohymenoptera are megasecopterous, we do not necessarily prove that they have no phylogenetic connection with the Hymenoptera. But if we still attempt to derive the Hymenoptera in this way, we at once remove the order from all the other holometabolous insects. This is precisely the view that Tillyard takes. He considers the Protohymenoptera to be a specialized offshoot of the common ancestor of the Megasecoptera, the Odonata and Protodonata, so that the Hymenoptera are thus more closely related to the Odonata than to the Mecoptera, Neuroptera, and the other panorpoid orders.

In this discussion I shall not review the evidence indicating that the Hymenoptera are derivatives of the same holometabolous complex which has produced the panorpoid orders, since that is the view that is generally accepted; but I shall attempt to refute the arguments which Tillyard advances to demonstrate that the Hymenoptera are derived from Protohymenoptera. To begin with, however, Tillyard first claims that the presence of a "complete archaic ovipositor" in the Protohymenoptera (*Asthenohymen*) is proof that the Hymenoptera are not members of the same complex which produced the panorpoid orders, since "the Hymenoptera are the only group of Holometabolous insects in which such an organ is developed." This is indeed an extraordinary statement, since in two groups of Neuroptera (suborder Raphidiodea, and the family Dilaridae) a similar, complete ovipositor occurs. Furthermore, as has been pointed out by several insect morphologists (e. g., Crampton, 1929), the ovipositor of the Hymenoptera is more similar to that of the Raphidiodea than it is to that of any hemimetabolous insect (Figure 4). So instead of being evidence that the Hymenoptera are not related to the panorpoid orders, the presence of an ovipositor in the Hymenoptera is strong evidence of just that relationship.

Tillyard's arguments for deriving the Hymenoptera from the Protohymenoptera are as follows (1936), pp. 451–452):

1) The general plan of the venation in Hymenoptera can be interpreted logically in terms of the venation of Protohymenoptera. Attempts to interpret it in terms of the venation of any other known order have not so far been successful.

2) The wing-membrane of the Hymenoptera is hard and glassy, as in the Protohymenoptera (and, incidentally, the Odonata).

3) The venational scheme of the Hymenoptera shows very strong main veins connected by strongly chitinized cross-veins which divide the wing into a rather small number of cells. The same type of venation occurs in the Protohymenoptera, and the venation of the Hymenoptera can be logically derived from that of the Protohymenoptera.

4) The structure of the head, antennae, and eyes in *Asthenohymen* are such that it could easily be the ancestor of the Hymenoptera.

5) The legs in *Asthenohymen* have only a three-

segmented tarsus. The tarsi in Hymenoptera are five-segmented. Therefore, the genus *Asthenohymen* cannot itself have been the ancestor of the order Hymenoptera. But it seems reasonable to suppose that *Asthenohymen* still is by far the most advanced member of the order in other respects, is also ahead of these more archaic genera in the structure of its tarsi, and that, therefore, the order Protohymenoptera, like the Coleoptera, may have included forms with five-segmented tarsi as well as forms with three-segmented tarsi.

6) The abdomen of *Asthenohymen* apparently possessed eleven segments and a pair of elongated cerci. There is nothing in this which precludes the Protohymenoptera from being considered as ancestors of the Hymenoptera, which, like all other winged insects, must have been descended from older types having the abdomen and cerci of this form.

7) The ovipositor of *Asthenohymen* is of the complete, archaic type. An ovipositor does not occur in the Megasecoptera. Therefore, the genus *Asthenohymen*, at any rate, cannot be descended from any known form of Megasecoptera, and the order Protohymenoptera should retain full ordinal rank and not be merged as a suborder of the Megasecoptera.

It is obvious that the last (7th) argument is concerned with the question of the relationship between the Protohymenoptera and Megasecoptera, and not with the ancestry of the Hymenoptera. It is also clear that the 5th and 6th of these arguments are purely of a negative nature, that is, they remove certain objections which might otherwise be advanced against the descent of the Hymenoptera from the Protohymenoptera.[4] The first and third arguments seem to me to be identical, both stating that the venation of the Hymenoptera can be interpreted logically in terms of the Protohymenoptera. But this conclusion neglects completely the question of convergent evolution of the venation, instances of which are innumerable among the insects. Furthermore the fact that Tillyard has interpreted the hymenopterous venation in two very different ways (see Tillyard, 1936, p. 448) on the basis of the assumed descent from the Protohymenoptera, and in both instances found the interpretation "logical," shows that the venation of the Protohymenoptera and Hymenoptera is not so similar as one might conclude from Tillyard's arguments. The same reply can be directed against the fourth argument, that the head, antennae, and eyes in *Asthenohymen* (the only genus of Protohymenoptera in which the head structure has been known) are such that it could easily be the ancestor of the Hymenoptera. Granting that this statement were true, it would not indicate that the Hymenoptera were descended from *Asthenohymen;* it would suggest that *Asthenohymen could have been* ancestral to the Hymenoptera and nothing more. Of course when Tillyard's statement was made very little was known of the head structure of *Asthenohymen* except the antennae and form of the eyes. But the discovery of the new specimens of *Asthenohymen* described above shows that the head in this genus was very specialized in possessing a rostrum, a type of head which could obviously *not* have been the source of origin of the generalized head of the Hymenoptera.

Tillyard's second argument, that the wing-membrane in the Hymenoptera is hard and glassy, as it is in the Protohymenoptera, fails again to take into consideration parallel evolution, for such a wing membrane has been developed in several unrelated groups of insects, such as the Homoptera and the Raphidiodea. The fact that the wing-membrane is glassy in both the Protohymenoptera and the Hymenoptera is therefore no proof whatsoever of the genetical relationship of the two orders.

Since these are the only arguments which Tillyard has been able to advance in support of his view of the evolution of the Hymenoptera, I consider that proof of that contention is utterly lacking and that Tillyard has not produced evidence to support his conclusions.

Although Tillyard concedes that the Protohymenoptera are closely related to the Megasecoptera, he maintains that the presence of the complete external ovipositor which I described in the Protohymenoptera (*Asthenohymen*) shows that this group could not be derived from the Megasecoptera, since "out of all the complete Megasecoptera already known, there is not a single one in which an ovipositor is present." The implication of this statement is, of course, that a great many complete specimens of Megasecoptera (aside from Protohymenoptera) are known. Let us examine the facts. At the present

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[4] As a matter of fact, I had previously suggested both of the possibilities mentioned by Tillyard (Psyche, 1930, 37: 371).

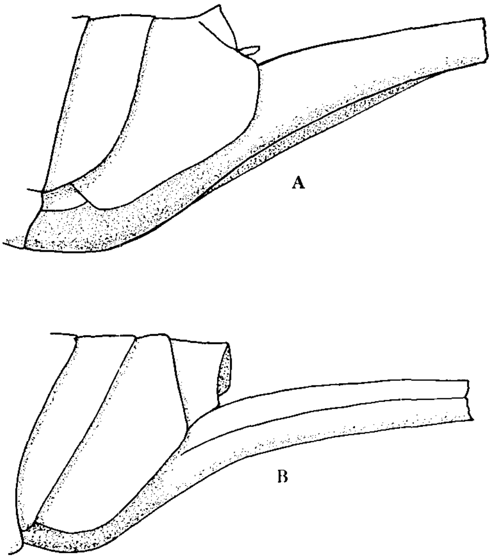

FIGURE 4. A. *Xyela* sp. (Recent, Hymenoptera), drawing of portion of ovipositor. B. *Agulla unicolor* Carp. (Recent, Raphidiodea), drawing of portion of ovipositor.

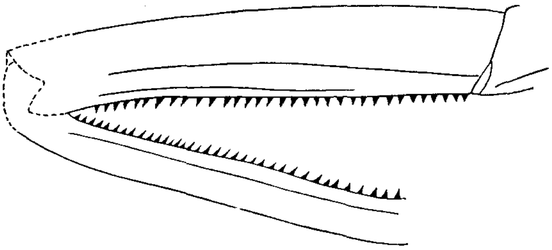

FIGURE 5. Protodonata sp., drawing of leg; specimen No. 4026ab, Museum of Comparative Zoölogy. Length, 48 mm.

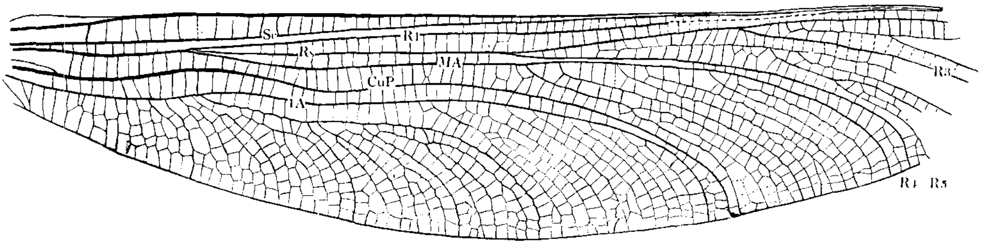

FIGURE 6. *Typus permianus* Sell., drawing of fore wing, No. 4021ab, Museum of Comparative Zoölogy.

time sixty species of Eumegasecoptera have been described.[5] These species are based upon a total of seventy-six specimens, which of course means that three quarters of the species, at least, are represented by unique specimens. An examination of the descriptions of these fossils reveals the fact that only twenty specimens at most show any signs at all of body structure. This, then, is the series to which Tillyard referred in his phrase, "all the complete Megasecoptera known." Now let us compare this number with that of the Protohymenoptera which have been described from the Elmo limestone alone. Including those mentioned in this paper, 143 specimens are contained in the Museum of Comparative Zoölogy. If we add to this the twenty-five in the Yale collection, then we have a total of 168 specimens of Protohymenoptera known from the Elmo limestone. Of this series a few more than forty specimens show parts of the body structure. In other words, more than twice as many Protohymenoptera as Eumegasecoptera have been studied, and twice as many of the Protohymenoptera as Eumegasecoptera have parts of the body preserved. Furthermore, the 168 Protohymenoptera have been derived from one formation and belong to only seven species; whereas the seventy-six Eumegasecoptera have been taken in several formations and belong to sixty species. It is not at all surprising therefore that we know more about the body structure of the Protohymenoptera than we do about that of the Eumegasecoptera. The tarsal segmentation, for example, is not satisfactorily known in any of the Eumegasecoptera, whereas the complete tarsi of all three pairs of legs are clearly preserved in several of the Protohymenoptera. Are we therefore justified in concluding that, since no ovipositor has been found so far in the Eumegasecoptera, these insects lacked an ovipositor?

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[5] The suborder Eumegasecoptera includes the typical Megasecoptera, *i.e.*, those not belonging to the suborder Protohymenoptera.

There are two other factors that bear on this same question. In the first place the Elmo limestone, in which most of the known Protohymenoptera have been found, is nearly white and is very fine-grained, and therefore gives much better preservation of details than is possible in the black and relatively coarse-grained Carboniferous shales, in which nearly all of the Eumegasecoptera have been collected. In the second place, the ovipositor is discernible, as such, in the Protohymenoptera only when the specimen is preserved in a lateral view. This is because the ovipositor projects only a very short distance beyond the end of the abdomen.[6] But so far as I have been able to determine from the descriptions, not one specimen of Eumegasecoptera has been found preserved in such a way as to show a lateral aspect of the abdomen.

In view of all these facts it is my opinion that there is no justification for Tillyard's assumption that the Eumegasecoptera did not possess an ovipositor, not for his exclusion of the Protohymenoptera from the order Megasecoptera on that assumption. On the contrary, it seems very probable that an ovipositor will turn out to have existed in the Eumegasecoptera when properly preserved specimens are found. As a matter of fact, however, the absence of an ovipositor in the Eumegasecoptera would not itself exclude the Protohymenoptera from the order Megasecoptera, for it may have been present in the common ancestor of the two groups (which Tillyard admits must have been true), and yet have been lost in one subsequent line of evolution (Eumegasecoptera). In such a case there would be no more justification for separating the Protohymenoptera and Eumegasecoptera into distinct orders, than there is for similarly separating the Dilardae, which have a complete ovipositor, from the rest of the Neuroptera, which lack an ovipositor.

Order PROTODONATA

The Protodonata collected in 1935 are unusually interesting. Since some of them have a direct bearing on the classification of the protodonate families, a discussion of this subject and of the evolution of the order is included after the actual description of the new specimens.

One specimen (No. 4026ab, upper layer) consisting only of the femur and tibia (figure 5) I consider to belong here because it is much too large to be referable to any other order which has been recognized in the Elmo limestone. It shows the armature of the protodonate leg better than any other fossils which have been found. The femur is 25 mm. long and the tibia, 23 mm. The inner surface of both segments is provided with heavy teeth, so closely arranged that the margins of the legs appear serrate. The tibia unquestionably has a double row of these teeth, for by chipping away its three distal teeth I exposed another series further down in the matrix. The femur possesses 23 teeth in a row, and the tibia 25 teeth. These show much individual variation in size, but this may be due to the fact that they do not actually arise in a straight line. It is not of course possible to determine even the generic position of the insect from which this leg was derived. The femur of the Carboniferous *Meganeura* was about one-sixth of the length of the wing, so that if the present specimen had wings of the same proportionate size, they must have been about 150 mm. long. This is much larger than the wing of *Typus permianus*, but is almost exactly the length of that of *T. readi* Carp.

The other Protodonata are as follows:

Family MEGANEURIDAE

Subfamily TYPINAE

The subfamily Typinae is represented in the Elmo limestone by three genera: *Typus* Sellards, *Megatypus* Tillyard, and *Oligotypus* Carpenter. The latter genus differs widely from the others by having a more poorly developed MA and a much more extensive Rs. The distinction between *Typus* and *Megatypus* is not so marked. The strongly formed "anal crossing" is probably the chief criterion of *Megatypus*. Tillyard considered the length of Sc a generic difference also, but as I have already pointed out Sc in *readi* is long, as in *Megatypus*, although the "anal crossing" is absent. The point of origin of MA, also given by Tillyard as a generic characteristic, is apparently subject to some variation in the Typinae. In my opinion, therefore, the distinctive "anal crossing" and the two rows of cellules between 1A and 2A, are the only features which serve to distinguish *Megatypus* from *Typus* satisfactorily.

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[6] It is true that the ovipositor is visible in one specimen of *Asthenohymen* preserved in dorsal view, as described in the foregoing pages; but the piece of the ovipositor is only 1 mm. long and its nature would not be obvious without the aid of a lateral specimen.

Typus permianus Sell.

Figure 6

Typus permianus Sellards, 1905, Amer. Journ. Sci., (4) 22: 249–258.

Typus permianus Tillyard, 1925, ibid., 10: 49.

Typus permianus Carpenter, 1931, ibid., (5) 21: 104.

Megatypus vetustus Carpenter, 1933, Proc. Amer. Acad. Arts Sciences, 68: 416.

Two of the 1935 specimens belong to *Typus permianus*, one (No. 4021ab, upper layer) consisting of a very nearly complete fore wing, and the other (No. 4023ab, upper layer) of the proximal two-thirds of a hind wing. A study of these fossils, which are the most nearly complete wings of this species found since the type specimen, shows that some confusion has existed regarding the venation of *permianus*, at least in my own mind, and I have found it necessary to restudy all the specimens of this species which are in the Harvard collection. The species was originally described from a single specimen, consisting of a more or less complete insect, with the four wings out-stretched (see photograph, Carpenter, 1931, p. 105). Unfortunately, the right hind wing was the only wing completely and clearly preserved, all the others either lacking the distal third or having it poorly preserved. Eleven years ago (1927) in Austin, Texas, I examined and photographed this type specimen. I also started several drawings of parts of the wings, but at that time Dr. Sellards kindly consented to loan his entire collection to me for study purposes at the Bussey Institution, and I postponed the completion of these figures. Only a few months later, however, before the collection could be packed for shipment, all the type specimens were either lost or destroyed. The drawing of the fore wing of *permianus* which was used in my 1931 account of the Kansas Permian Protodonata was therefore based mainly on the photograph of the type and the incomplete drawings. From my examination of the newly acquired fore wing of *permianus*, I am convinced that this 1931 drawing does not depict with entire accuracy the venation of this species. In the first place, there should be a sector between R3 and R4 + 5. I am at a loss to explain why this sector was not included in my previous drawing, for although it was not clearly preserved in the fore wings of the type, it was distinct in the right hind wing and was drawn by Sellards. In the second place there should be fewer cellules between 1A and the hind margin at the base of the wing than are shown in my 1931 figure, this part of the wing also being more nearly correctly drawn by Sellards. In the accompanying figure I have included a drawing of the new fossil which is almost a complete wing (No. 4021). A comparison of this with the descriptions and figures given by Sellards leaves no doubt that it is *permianus*.

With the venation of *permianus* clarified, it is obvious that *Megatypus vetustus*, which I described from a distal third of a wing in 1933, is *Typus permianus*. A slight individual variation in the position of origin of R4 + 5 is undoubtedly sufficient to explain my error in assigning this specimen to *Megatypus;* and once in *Typus*, it is clearly *permianus*.

The restudy of the venation of *permianus* leading to the conclusion that Sellards' figures of *permianus* were more nearly correct than either Tillyard or I had supposed, raises the question of the presence of the subnodus and the so-called oblique vein ("O") which Sellards described between the base of "M2" (R3) and "Rs" (sector) below it. My intention to examine Sellards' type for these structures was of course frustrated by the loss of the specimen before it was sent to me. Tillyard had examined a photograph of the type sent to him by Sellards, and, seeing no sign of the oblique vein, was apparently led to the conclusion that it was not present. He implies the same about the subnodus. I have seen no specimens with the latter preserved, but it should be noted that in all the specimens of *permianus* in the Harvard collection showing this area of the wing, the part where the subnodus would be located is broken away.[7] So far as Sellards' oblique vein ("O") is concerned, it is true that such a vein does occur in some specimens of *permianus*, but the slope of the vein is subject to much variation and at times the vein is practically perpendicular to the lower vein it joins.

Typus readi Carp.

Figure 7

Typus readi Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 415, fig. 1.

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[7] The unnamed fragment of a Protodonatan, figured in part 6 of this series (p. 417), has a short vein present in the position of Sellards' subnodus, but several odonatologists and other entomologists have expressed the opinion to me that the peculiar structure of this wing was probably the result of an injury to the nymphal wing pad.

This species was originally based upon a well preserved hind wing, lacking the proximal and distal parts. In the 1935 collection there is a specimen of a wing (No. 4022ab, upper layer), which I consider to be a fore wing of this species. That it is a fore wing is clearly shown by the relatively narrow anal region, and the more gradually undulated CuP and 1A. This wing possesses the two chief characteristics of *readi:* (1) the subcosta does not terminate until at least almost the apex of the wing, so that in the region above the point of separation of R2 and R3 it is much further from the costa than it is in *permianus;* (2) R4 + 5 arises at a point well proximad of the origin of the first branch of MA. The new specimen is 100 mm. long and 30 mm. wide, which indicates that the whole wing was almost exactly the size of the holotype. The similarity of the venation of the two wings is very striking, the origin of even the[8] minor veins being almost identical in position. The fore wing (No. 4022ab) is 105 mm. long and has a maximum diameter of 30 mm. Unfortunately, as in the type, the area just above the forking of R2 + 3 is partially broken away in the fore wing, so that we are unable to determine whether or not the structure of this part of the venation is like that described by Sellards in *permianus.*

In all probability the specimen (No. 5009, Peabody Museum) which Tillyard figured and described as the fore wing of *Megatypus schucherti* (1925, p. 57, fig. 8) belongs to *readi.* Tillyard stated in his account of this poorly preserved fragment that its venation differed from that of the hind wing (previously described) "only" in the much narrower anal area; but, as shown in his figure, the most significant difference is that in the fragment of the fore wing, R4 + 5[9] arises far *proximad* of the origin of the first branch of MA, and not far *distad* of the origin of the latter, which was true of the hind wing, and which Tillyard selected as one of the characteristics of the genus *Megatypus.* This difference clearly indicates that the two specimens do not belong to the same species. Since the early origin of Rs is the chief characteristic of *Typus readi,* it is very probable that the fragment of the fore wing belongs to *readi.*[10]

Megatypus ingentissimus Till.

Megatypus ingentissimus Tillyard, 1925, Amer. Journ. Sci., (5) 10: 58, fig. 9.

In his account of the small fragment on which this species was based Tillyard attempted to estimate the size of the complete wing by comparing the distances between the apex and the end of R4 + 5 (R3 of Tillyard's figure) in this fossil and in *Typus permianus.* He concluded that the complete wing must have measured over 250 mm., which is only a little short of the size of *Meganeura.* Unfortunately, there seems to have been an error in Tillyard's computation. The distance from the end of R4 + 5 to the apex of the wing in *T. permianus* is one-fifth of the entire length of the wing. In the specimen of *M. ingentissimus* this same distance is 24 mm., which would indicate that the total wing length was not over 125 mm., about half the dimension estimated by Tillyard. This is consistent with the size of the veins and cells as actually preserved in the fragment. The question of the size of *ingentissimus* arose in my mind in connection with the identification of *Meganeuropsis permiana,* described in this paper.

It should be noted also that there is really no evidence indicating that this species belongs to *Megatypus,* since the long Sc, as I have mentioned above, is also present in *Typus.*

Subfamily MEGANEURINAE

Meganeuropsis, new genus

Allied to *Meganeura,* but differing in having the proximal part of the costa curved, and the proximal portions of CuP and 1A almost straight.

Meganeuropsis permiana, n. sp.

Figure 8

This species is based upon two fragments of a wing: one (No. 4024) consists of the proximal region, from the base to a point well beyond the origin of R4 + 5; the other (No. 4025) consists of the area between R4 + 5 and 1A, in the region of the first branch of MA. Both of these fossils were collected by the writer and were undoubtedly parts of one individual insect. The proximal piece was found first about a half inch below the top of the upper layer of the limestone. Unfortunately, the latter was already broken up into irregular pieces by underground weathering (see plate 1, fig. 1) so that an attempt to follow the wing along at the same level in the limestone was only partially successful. The second portion of a wing was found at exactly the same level in a block of the limestone less than two feet away from the place where the first fragment was secured. Since no other specimen of this species or genus has been found in the limestone, I am convinced, as stated above, that the two fragments are part of the same individual. In order to determine the relationship between the fragments, drawings of each were made to the same scale, that of the second piece being made on tracing paper. It was found that the two fragments fitted together very readily but also that there was slight overlapping of the areas included. The fragments are therefore not portions of the same wing.

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[8] Further cleaning of the type specimen of *readi* (No. 3253ab) reveals a sector between R2 and R3, at the very apex of the fossil, which was not included in my original figures of *readi.*

[9] In this descripions and discussions of *Megatypus* Tillyard designated R4 + 5 as R3, but he corrected this error in a later paper (1928, p. 161).

[10] Following his description of the two specimens of *schucherti,* Tillyard designated *both* of them as holotypes (p. 58),—one as the holotype hind wing, the other as the holotype fore wing. However, not by any accepted definition of a holotype is it possible to have *two* holotype specimens of one species; even the obverse and reverse of a holotype specimen are only counterparts of the one type. The true holotype of *schucherti* is the specimen of the hind wing (No. 1021ab), since that was described and designated as the holotype first. The fragment of the fore wing is of course only a paratype.

The proximal fragment (No. 4024, figure 8A) is 140 mm. in length, from the base of R + M to the broken end of MA. This piece of the wing having been covered by and infiltrated with calcite, only a few of the cross-veins are discernible, but it is not difficult to determine the structure of the main veins. Only the proximal piece of the precostal space is evident; the width of this, however, indicates that the rest of the area was about the same as that in *Meganeura*. The costa is close to the subcosta at the base, but soon curves anteriorly. R is distinctly independent from the stem of M, as in *Meganeura*, and diverges away from MA at a point just above the highest crest of CuP. Rs apparently arises at this separation, but its exact origin is not discernible. Although the area between Rs and MA is very poorly preserved, it is possible to distinguish clearly R4 + 5; the precise origin of this vein cannot be determined, but it is obviously located not far from the origin of Rs, this being the chief characteristic of the subfamily Meganeurinae. In all probability these two veins separate at a narrow fork instead of by an abrupt divergence of one of them.[11] CuP and 1A are formed as in *Meganeura* except that their proximal parts are nearly straight. The true margin of the wing is not visible anywhere in this specimen, and it is impossible to determine how broad the wing actually was; but in view of the shape of the wings of *Meganeura*, it was probably half again as wide as the preserved portion. The few cross-veins that are preserved indicate an arrangement similar to that of *Meganeura*. In the area between CuP and 1A there is a single oblique cross-vein, similar to the one or two present in *Typus*. Although this fragment (No. 4024ab) of the wing is not so well preserved as the more distal piece, it includes the important taxonomic characters and is therefore designated as the holotype of the species.

The second piece (No. 4025ab, paratype) of this species is perfectly preserved. The first branch of MA arises at the same point, with respect to the curvature of CuP, as it does in *Meganeura*, and it forms a distinct fork, as in the latter. 1A gives rise to a series of straight veinlets, as is characteristic of the subfamily Meganeurinae.

When these two fragments are fitted together, it becomes apparent that in spite of the perfect correspondence in other details, the distance between R4 + 5 and MA is greater in the second (distal) piece than in the first; and it is also clear that R4 + 5 is straight, not curved upward to meet R2 + 3, as seems to be the case in the proximal fragment. In this respect, R4 + 5 of the second piece is formed exactly as it is drawn by Brongniart in *Meganeura monyi* (1893, plate 25). The most likely explanation of these differences is that one fragment is part of a hind wing and another part of a fore wing, and this view is substantiated by the fact that the various wing fragments of *Meganeura* show a similar difference of structure. Unfortunately, not enough well preserved specimens of *Meganeura* have been found to indicate which is the fore or hind wing.

Like *M. monyi*, *Meganeuropsis permiana* was a huge insect. The fore wing of *monyi,* which has been recognized as the largest insect so far discovered, was about 300 mm. (or 12 inches) in length, the entire wing expanse being about 27 inches. In order to obtain an estimation of the size of *M. permiana,* a drawing of the type specimen was made on tracing paper and placed over Brongniart's figure (natural size) of the wing of *M. monyi.* This comparison showed that the wing of *M. permiana* was slightly larger than that of *monyi.* If the wings of the former were shaped like those of *monyi,* then the wing of *permiana* must have been about 330 mm. (or about 13 inches) long, indicating a wing expanse of approximately 29 inches (710 mm.). Because of the fragmentary condition of the specimens of *Meganeuropsis permiana,* it is difficult to indicate differences between *Meganeuropsis* and *Meganeura;* but I have considered it preferable to erect a new genus for this species, rather than to place it in *Meganeura,* thus extending the range of that genus to the Permian and to the New World.

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[11] In this connection it should be noted that much confusion has existed in the literature regarding the origin of Rs and R4 + 5 in *Meganeura*. Lameere (1917) has pointed out that Brongniart's original restoration (1892) on plate 25 is correct, although the drawings of the actual fossils on the preceding plate are inaccurate. The restorations by Handlirsch (1908, 1920) and Tillyard (1917) followed the latter drawings and are consequently incorrect. In another paper (1919) by Handlirsch, the reconstruction of the meganeurid venation depicts the origins of Rs and R4 + 5 as they were originally restored by Brongniart.

The occurrence of *M. permiana* in the Elmo limestone furnishes another illustration of the diversity of structure among the insects of this Permian deposit. In the same fauna there existed such minute insects as the Psocopteron *Cyphoneura permiana* Carp., with a wing expanse of less than 3/8 of an inch (4 mm.). No other known insect fauna, Recent or fossil, exhibits such diversity in size.

THE CLASSIFICATION AND EVOLUTION OF THE PROTODONATA

During the past ten years the clssification of the Protodonata has been discussed and modified by several students of fossil insects. Handlirsch in his catalogue of Palaeozoic insects (1922) recognized four families in this order: Paralogidae, Meganeuridae, Protagriidae, and Typidae. Following the publication of Lameere's theory of wing venation in 1921, Tillyard proposed (1925) that the order be divided into two families: Protagriidae, including those species in which MP and CuA were fully developed; and Meganeuridae, in which MP and CuA were absent or possibly reduced to mere vestiges at the base of the wing. The latter family he divided into three subfamilies, Paraloginae, Meganeurinae, and Typinae. This classification was used in my 1931 account of the Kansan Protodonata, though I stated that in my opinion the characteristics separating the families Protagriidae and Meganeuridae were of subordinal rather than family rank. A similar treatment of the families was independently advocated by Martynov (1932), who proposed further separation of the family Meganeuridae by establishing for it a new order, Meganisoptera. At the same time he erected a new family (Calvertiellidae) for the genus *Calvertiella* from the Kansan Permian, and following Lameere transferred the family Cockerelliellidae from the Palaeodictyoptera to the Protodonata. Martynov therefore considers the order Protodonata to consist of three families: Protagriidae, Calvertiellidae, and Cockerelliellidae. Later in 1932 Martynov was led to conclude that the insects comprising the order Meganisoptera were not sufficiently different from the true Odonata to justify their exclusion from that order, and therefore placed the family Meganeuridae, with its subfamilies, in the Odonata. Tillyard, in his latest and last discussion of the subject, accepts Martynov's proposal of isolating the Meganeuridae from the Protodonata, but also favors their exclusion from the Odonata because of their lack of a true nodus.

In my opinion there is no justification for isolating the Meganeuridae from the rest of the families formerly included in the Protodonata, until it has been proven that the Meganeuridae have had a phylogenetic origin different from that of the other families. At the present time there seem to be no facts to support such a conclusion. It is also my opinion that the Meganeuridae should be excluded from the true Odonata until evidence has been secured showing that the Meganeuridae are in the phylogenetic line leading directly to the Odonata or that they have been derived from the *immediate* ancestor of the Odonata. There are undoubtedly many points of similarities between the Meganeuridae and the Odonata, but these I believe to be characteristics which were present in the remote common ancestors of the two groups, or which have appeared in the Meganeuridae and Odonata as a result of parallel evolution. The more important of the similarities between the members of these two categories, as indicated by a comparison of the Protanisoptera with the Meganeuridae, are the absence of MP and CuA, the distinctive origins of Rs and MA, the presence of the supposed remnant of CuA at the base of the wing, and the undulation of CuP. All of these characteristics, I believe, were possessed by the common ancestor of the Meganeuridae and the Odonata. My reasons for this conclusion will be given below.

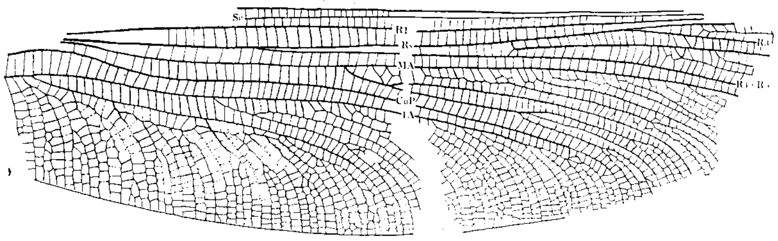
Sc
R1
Rs
MA
CuP
1A

FIGURE 7. *Typus readi* Carp., drawing of fore wing; No. 4022ab, Museum of Comparative Zoölogy.

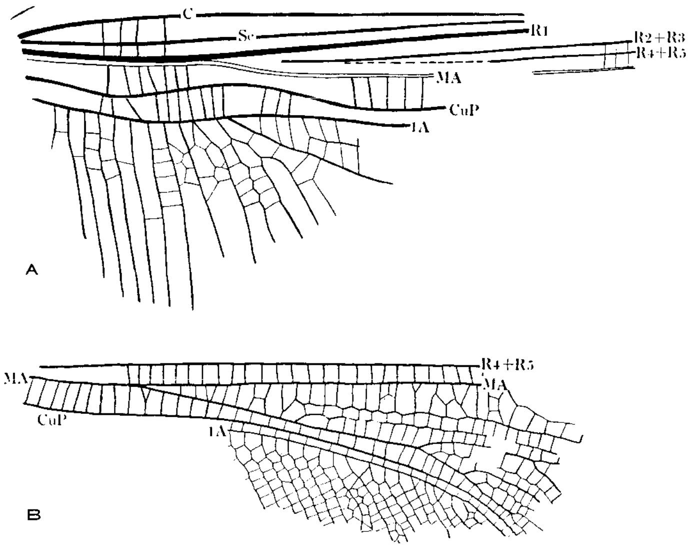
C
Sc
R1
R2+R3
R4+R5
MA
CuP
1A
A
MA
R4+R5
MA
CuP
1A
B

FIGURE 8. *Meganeuropsis permiana*, n. sp., drawings of venation. A, holotype, No. 4024ab; B, paratype, No. 4025ab, Museum of Comparative Zoölogy.

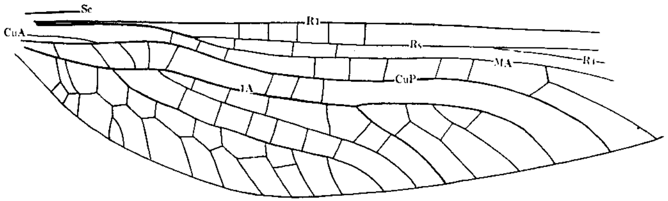
Sc
CuA
R1
Rs
MA
CuP
1A

FIGURE 9. *Erasipteron larischi* Pruvost, drawn from photograph. Carboniferous, Czechoslovakia.

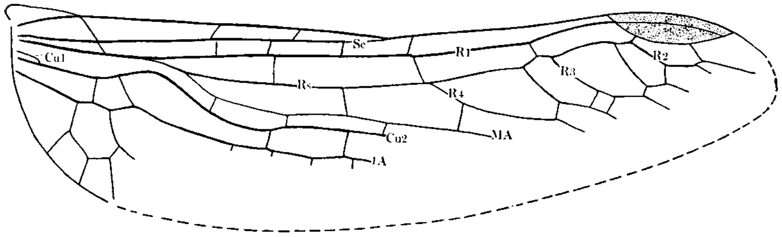
Cu1
Sc
R1
Rs
R4
R3
R2
Cu2
MA
1A

FIGURE 10. *Ditaxineura anomalostigma* Till., drawing of hind wing; specimen No. 3972ab, Museum of Comparative Zoölogy.

The absence of the nodus from the Meganeuridae, although removing them from the true Odonata, does not necessarily eliminate them from the phylogenetic line leading to the Odonata. But the most striking difference between the Meganeuridae and the most generalized Odonata (whether termed Protanisoptera, Permanisoptera, or Permodonata) is in the number of cells in the wings. In the fore wing of *Typus permianus*, for example, which is typical of the Meganeuridae so far as the number of cross-veins is concerned, there are upwards of a thousand cells. In the Protanisoptera, however, there are at the most two hundred (*Polytaxineura*, *Permaeschna*, *Pholoptilon*), with less than 100 in *Ditaxineura*, the oldest and most generalized of the anisopterous Odonata. It seems apparent to me that the network of cellules in the Meganeuridae is a specialization not to be expected in the ancestor of the Odonata. For this reason, following a study of the Permian Odonata in 1931, I was led to the conclusion that the families of Protodonata known to us were really highly specialized members of the order, and that the "earliest and most primitive representatives were much more like the forms which we postulate as ancestors of the true Odonata."

Much support has been given to this view by the subsequent discovery of the protodonatan, *Erasipteron larischi* Pruvost (1934), from the Upper Carboniferous (Upper Namurian) of Czechoslovakia. The importance of this fossil lies in the fact that it is geologically *the oldest known member of the order*. A drawing of the specimen, made from a photograph kindly sent to me by Dr. Pruvost, is included here (figure 9). This fossil consists of a well preserved wing, probably a fore wing, which lacks the anterior margin and the apical region. The most striking feature of the wing is the relatively small number of cross-veins. On the basis of the structure of the preserved part of the wing, it is probable that the complete wing included less than a hundred cells, about the same number as is present in *Ditaxineura*. In addition the wing of *Erasipteron* has also all of the odonate characteristics previously mentioned which are common to the Meganeuridae and the Protanisoptera—the absence of MP and CuA, the distinctive origin of Rs and M, the undulation of CuP, and the supposed remnant of CuA. The loss of a complete MP and the presence of the supposed remnant of CuA are especially interesting, since they show that the reduction of MP and CuA occurred as far back as the lower part of the Upper Carboniferous, before the deposition of the Commentry shales. It is unfortunate that the nodal region of the *Erasipteron* wing is not preserved; in all probability an incipient nodus was present. In my opinion the ancestors of the true Odonata were very much like *Erasipteron* (though it is improbable that *Erasipteron* itself was in the direct line of that ancestry), rather than like *Meganeura* or any of the other Meganeuridae. Pruvost assigned *Erasipteron* to the family Paralogidae, which has previously been known only from the Carboniferous of North America. The distinctive feature of the Paralogidae is the very short subcosta, which is not preserved in the type of *Erasipteron*. The wings of the Paralogidae, however, are as closely netted with cellules as those of the Meganeuridae. With its small number of cells the genus *Erasipteron* is unique among all the Protodonata and it unquestionably requires the erection of a separate family, **Erasipteridae** (new family) for its reception. The position of this family in the Protodonata is apparent from the following table which summarizes my present conception of the classification of the families of the order:[12]

Suborder **Euprotodonata,** new suborder (MP and CuA present).
  1. Family Protagriidae, Handl. Upper Carboniferous of Europe.
  2. Family Calvertiellidae Mart. Permian of Kansas.

Suborder Meganisoptera Mart. (MP absent, CuA absent or possibly vestigial).
  1. Family Erasipteridae, new family. Upper Carboniferous of Europe.
  2. Family Paralogidae Handl. Upper Carboniferous of North America.
  3. Family Meganeuridae Handl. Upper Carboniferous of Europe, Permian of Kansas, Arizona, Russia.
     A. Subfamily Meganeurinae Handl. Upper Carboniferous of Europe, Permian of Kansas.
     B. Subfamily Typinae Handl. Permian of Kansas, Arizona, Russia.

In this table I have regarded the Meganeurinae and Typinae as separate subfamilies rather than as families, as they have been treated by Handlirsch. It is true that there are more differences between the members of these two subfamilies than have previously been recognized. Tillyard stated (1928, p. 162) that the Typinae differ from the Meganeurinae "only" in having R4 + 5 arise far distad of the origin of MA; but in addition to this there are also other differences: the precostal space, which is limited to the very base of the wing in the Typinae, extends to the middle of the wing in the Meganeurinae; the first branch of MA arises at the middle of the wing in the Typinae, but in the proximal half of the wing in the Meganeurinae; and the branches extending from the sectors of 1A to the hind margin are curved in the Typinae but are almost straight in the Meganeurinae. These differences, however, seem hardly sufficient to justify separation of the groups by family ranking.

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[12] The family Cockerelliellidae is omitted from this list, since I consider it to be a Palaeodictyopteron, rather than a Protodonatan.

Until the present time the subfamily Meganeurinae has been found only in the Upper Carboniferous of Europe. The occurrence of *Meganeuropsis*, which is unquestionably a true meganeurine, in the limestone is therefore of much interest. This fossil not only extends the geological range of the Meganeurinae into the Permian, but extends likewise its geographical range into the New World.

Order ODONATA

True Odonata are among the rarest of the insects occurring in the Elmo limestone. Up to the time when the 1935 collection was secured, only 13 specimens were contained in the combined Sellards (1), Yale (4) and Harvard (8) collections. In the new material there are 7 more specimens, which bring the total to 20 and add in many respects to our knowledge of the structure of these earliest Odonata.

Suborder Protanisoptera

Family DITAXINEURIDAE

Ditaxineura anomalostigma Till.

Figure 10

Ditaxineura anomalostigma Tillyard 1926, Amer. Journ. Sci., (5) 11: 71–73.

Ditaxineura anomalostigma Carpenter, 1931, ibid., (5) 21: 123–124.

Two specimens of this insect were found in 1935, both in the upper layer. One of these (No. 4027) consists of the distal half of a fore wing, and deserves no further comment. The other (No. 3972) is an incomplete hind wing, which, although lacking part of the posterior area, contains those portions of the venation of greatest phylogenetic interest. This fossil is therefore a most important one, since it is the first specimen of a protanisopterous hind wing which has been found (with the exception of a very minute fragment, figured by Tillyard in 1935, from the Upper Permian of Australia). This hind wing is 19 mm. long, a little shorter than the fore wing (21 mm.), which I have previously described in detail (1931).[13] The width at the proximal part of the wing (the only part of the fossil which includes the posterior margin) is 4.6 mm. This is somewhat greater than the width of the same part of the fore wing, which measures 2 mm. The maximum width of the fore wing, at about the middle line of the wing, is 5 mm., and it is probable that the maximum width of the hind wing was not much greater than the proximal width. The precostal area of the hind wing is similar to that of the fore, and R1, Rs, and the pterostigma are essentially the same as in the fore. Sc, however, terminates almost exactly at the middle of the wing, which is more proximad than in the fore wing. This difference between the fore and hind wings is one that is also found in the existing Anisoptera. The region of the arculus is of course especially interesting. As in the fore wing, M is coalesced proximally with Rs, but Rs + M diverges from R much more abruptly than it does in the fore wing; this is also true of the separation of M from Rs. The result of these abrupt divergences is to produce a condition which is a definite approach to the structure of the arculus in the Jurassic *Tarsophlebia* (Anisozygoptera). The small vein at the base of the wing, designated as Cu1, is well developed. Cu2 is strongly undulated, much more so than it is in the fore wing, but this is not true of 1A; as a result of the form of these two veins, the space between them is greater than in the fore wing. The area between 1A and the posterior margin is considerably wider than in the fore wing; in this area there has been an increase in the number of rows of cells.

From the foregoing account it is apparent that the hind wing of *D. anomalostigma* differs from the fore wing chiefly in four respects: (1) the broader anal area; (2) the shorter Sc (more proximal nodus); (3) more abrupt divergence of Rs and M at their origins; and (4) greater curvature of Cu2. The significance of these differences is that they are the same as those which exist between the fore and hind wings of the Recent

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[13] As a result of a misprint, the length of this wing was published as "2.1" mm., instead of "21" mm. (1931, p. 123).

Anisoptera and the extinct Anisozygoptera. Such a condition is in perfect agreement with the view that the Protanisoptera were ancestral to the true Anisoptera.

Since my previous discussion of the Protanisoptera was written (1935) Tillyard has described from the Upper Permian of Australia (1935) another genus, *Polytaxineura,* which belongs to this suborder. In view of the similarity between *Polytaxineura* and *Pholidoptilon* Zalessky (from the Upper Permian of Russia), Tillyard placed these genera in one family. This family he termed Polytaxineuridae, stating that Zalessky did not propose a family name for *Pholidoptilon.* Unfortunately he seems to have overlooked Zalessky's use of the name Pholidoptilidae for the family to include his genus; this name was actually proposed by Zalessky with his description of the genus (1931a, 1931b) and of course has priority over the name Polytaxineuridae.

Suborder Protozygoptera

Family KENNEDYIDAE

Kennedya mirabilis Tillyard

Figure 11

Kennedya mirabilis Tillyard, 1925, Amer. Journ. Sci., (5) 10: 66–72.

Kennedya mirabilis Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 418.

One specimen of this rare insect (No. 3971ab, upper layer) was found in 1935; it is the first complete wing of the species and genus which has been secured. The venation is almost identical with that of the type specimens, and the differences that do exist, such as in arrangement of the cross-veins at the end of M, are hardly more than individual variations.[14] The wing has a length of 25 mm., and a maximum width of 3.3 mm. It is accordingly very much smaller than the type, which is 44 mm. long and 5.8 mm. wide. Although this is a decidedly greater variation in size than usually occurs in Odonata (a ratio of .56), Professor Calvert has called my attention to a record of an even greater variation in a Recent Zygopteron, *Megaloprepus caerulatus* (Drury) (Calvert, 1923).[15] Regardless of the striking difference in the wing length between the type and the present specimen, therefore, I regard them as belonging to the same species.

A second specimen of *Kennedya* (No. 3974ab) may also belong to *mirabilis;* it consists of the distal half of a poorly preserved wing.

Kennedya tillyardi, n. sp.

Figure 12

Fore wing: Length 33 mm., maximum width, 4 mm. Petiole longer and more slender than that of *mirabilis;* two antenodals, more widely separated than in *mirabilis;* 4 postnodals; pterostigma about twice as long as in *mirabilis;* Rs and MA arising as in the latter, but MA with a prominent upward curve a short distance beyond its origin; R4 + 5 arising at about the middle of the wing; branches of Rs as in *mirabilis,* except that at least one cross-vein is present between 1R2 and R2; stem Cu2 + 1A slightly more curved than in *mirabilis;* fork of Cu2 and 1A narrow, Cu2 at this point being very close to the origin of MA; m-cu cross-vein very oblique, almost parallel with the longitudinal axis of the wing; 1A much closer to the hind margin than in *mirabilis.*

Holotype: No. 3970ab, Museum of Comparative Zoölogy; collected by F. M. Carpenter in the upper layer of the Elmo limestone. The specimen consists of a fore wing, complete except for a slight tear in the posterior margin near the apex. The species is named for the late Dr. R. J. Tillyard.

Although this wing is similar to that of *mirabilis* in general features, the longer petiole and stigma, and the position of 1A show beyond doubt that it represents a distinct species.

Kennedya reducta, n. sp.

Figure 13

Based upon the distal third of a wing. Length of fragment 11 mm.; width 3.6 mm.; pterostigma short, as in *mirabilis,* R2 + 3 remote from R1; 1R2 separating from R2 below the pterostigma; no cross-veins between 1R2 and R2; R3 arising slightly proximad of the pterostigma, only one cross-vein between it and 1R2; 1R3 arising almost directly above the end of 1A, only two cross-veins between it and R3, and only three cross-veins between 1R3 and R4 + 5.

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[14] It should be noted that in Tillyard's figure of *mirabilis* (1925, fig. 10) the veinlets between Cu2 and the posterior margin are not correctly drawn; they should be somewhat oblique and sigmoidal, as shown in his photograph (figure 12B).

[15] I am indebted to Professors C. H. Kennedy and P. P. Calvert for their opinions on the significance of the difference in size of the specimens of *K. mirabilis.*

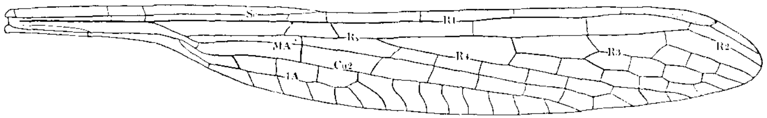
Sc
R1
Rs
MA
R4
Cu2
1A
R3
R2

FIGURE 11. *Kennedya mirabilis* Till., drawing of venation; specimen No. 3971ab, Museum of Comparative Zoölogy.

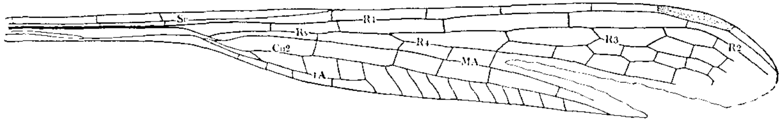
Sc
R1
Rs
Cu2
R4
MA
1A
R3
R2

FIGURE 12. *Kennedya tillyardi* n. sp., drawing of venation; holotype, No. 3970ab, Museum of Comparative Zoölogy.

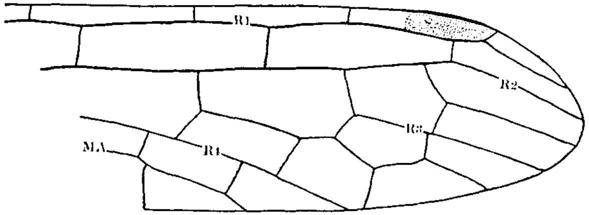
R1
R2
R3
MA
R4

FIGURE 13. *Kennedya reducta* n. sp., drawing of venation; holotype, No. 3973ab, Museum of Comparative Zoölogy.

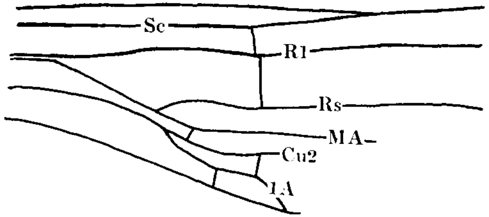
Sc
R1
Rs
MA
Cu2
1A

FIGURE 14. *Progoneura minuta* Carp., drawing of arculus region; specimen No. 3975, Museum of Comparative Zoölogy.

Holotype: No. 3973ab, Museum of Comparative Zoölogy, collected by F. M. Carpenter in the upper layer of the Elmo limestone in 1935. This specimen consists of a splendidly preserved distal third of a wing.

A comparison of this wing with that of *mirabilis* indicates that the complete wing was probably about 35 mm. long, nearly the same size as the type of *tillyardi*. The wing differs from that of the other species of *Kennedya*, and of all other described Protozygoptera, by the small number of cells in the region of the branches of Rs; thus, between R3 and R4 + 5 there are only 2 cells in *reducta* instead of 5 or 6, as in *mirabilis* and *tillyardi*. If the same condition prevails throughout the rest of the wing, it may eventually be found advisable to establish a distinct genus for *reducta*.

Progoneura minuta Carp.

Figure 14

Progoneura minuta Carpenter, 1931, Amer. Journ. Sci., (5) 21: 120.

Although only a fragment of a wing of this species was also found in 1935, this specimen (No. 3975, upper layer) is of interest because it includes the arculus region and details which are better preserved than those in the other two known specimens. My figure of this region in the type specimen (p. 117) was necessarily diagrammatic because of the poor preservation; I therefore include here a drawing of the arculus of the new specimen. The proximal cross-vein between R1 and Rs is present, as in the other species of Kennedyidae. The stem of Rs + MA is even longer than I had supposed it to be. The fossil shows clearly the chief characteristic which separates this genus from *Kennedya*: the very short 1A, terminating almost directly below the arculus.

Order HOMOPTERA

Some of the most interesting insects found in 1935 are Homoptera. Twenty-six specimens were collected, all but five being derived from the upper layer of the limestone. Although no undescribed species were secured, the new lot of fossils is significant because of its contribution to our knowledge of the body structure and hind wings of these earliest Homoptera.

A study of the additional Homoptera shows that the classification of the Lower Permian species needs to be greatly modified. In 1931, in my first account of these insects, I concluded that all the Lower Permian Homoptera which had been described were members of the family Archescytinidae, and both Tillyard and Martynov have accepted this view. In later papers (1931, 1933) I established two other families for the Lower Permian Homoptera, Cyphoneuridae (1931) and Lithoscytinidae (1933). The former was erected for two species, consisting of wings with a very reduced venation, which were closely related to the genus *Lophioneura* Till. (Permian of Australia), placed by Tillyard (1921) in the Homoptera. More recently, however, Tillyard secured several nearly complete members of this same group of insects and from his examination of them concluded (1935) that the mouth-parts were mandibulate, and that the whole series of insects belonged to the Psocoptera. As I mentioned at the time of the description of *Cyphoneura*, I suspected the possibility of the affinities of these insects with the Psocoptera on the basis of the wing venation, but believed that most of the evidence pointed to the Homoptera. Since Tillyard's conclusion seems fairly certain, we may, tentatively, at least, consider the family Cyphoneuridae as not homopterous.

The second family, Lithoscytinidae, was established to include a remarkable wing which differed from all other Homoptera by having Cu1 entirely free from the media for its entire length. Except for this striking peculiarity, this wing was like those of the Archescytinidae. Martynov had then just described (February, 1933) several archescytinids from the Upper Permian of Russia, including one hind wing which was more triangular than the fore wings and had all the characteristics that would be expected in the hind wing of the Archescytinidae. Now one of the archescytinids (*Permoscytina kansasensis*) collected in 1935 is fairly complete, including both fore and hind wings. The hind wing is not at all like the one which Martynov described as an archescytinid, for it has the free Cu1 of *Lithoscytina* (figure 17). The latter genus, therefore, was obviously founded upon the hind wing of an archescytinid. The family Lithoscytinidae consequently becomes synonymous with the Archescytinidae, which remains the only family of Homoptera so far known from the Lower Permian.

It is also necessary to make some changes in the generic classification of the Archescytinidae. The genus *Archescytina* itself was established by Tillyard for one species represented by a very well preserved wing, the outstanding characteristic of which was a well developed subcosta, remote from the radius for its entire length. This venational feature was an important one since in no other Homoptera has a similar condition of Sc been known. None of the three incomplete wings of this species which were contained in the 1927 Harvard collection showed the area between the costal margin and the radius satisfactorily, and I assumed that my inability to discern the subcosta in those specimens was the result of their poor preservation. Only the reverse of the type was at that time (1931) in the Peabody Museum, the obverse still being in Dr. Tillyard's possession; consequently when I failed to find Sc in the reverse of the type, the costal area of which was not well preserved, I concluded that it was undoubtedly clear enough in the obverse. However, my suspicions about the structure of the subcosta were aroused when several specimens in the 1935 collection were found to be identical with Archescytina except that the subcosta was formed as in the other Permian Homoptera. Meanwhile, the obverse of the type of *Archescytina permiana* had been returned to the Peabody Museum by Dr. Tillyard, and an examination of this fossil failed to reveal any sign whatever of a free and isolated subcosta.[16] A photograph of the obverse of this type is shown in plate 2, figure 1. This is more than a mere taxonomic correction, for because of the supposed free subcosta, *Archescytina* has been regarded as the most generalized of the known Homoptera, and Tillyard's figure of has it been reproduced in various publications by other students of insect phylogeny.

The removal of this supposedly distinctive feature places *Archescytina* very close to the other genera of Archescytinidae. In fact it is difficult to find generic characteristics in the wings by which to separate *Archescytina* from *Permopsylla*. The only characteristic which might be accepted as of generic value is the longer free Cu1 in the fore wing of *Archescytina*. This is a slight difference to be sure but it nevertheless seems advisable not to synonymize *Permopsylla* with *Archescytina* until the body structures have been found to be similar. *Permoscytina* is still a valid genus. The genotype, *kansasensis*, differs markedly in having R + M straight, not arched as in *Archescytina* or *Permopsylla*. This characteristic is very clearly indicated in the type of *kansasensis* (photograph, Tillyard, 1926, p. 384), and also in a new specimen contained in the 1935 collection. However, it is now necessary to make a change in the generic position of *Permoscytina muiri* Till. Tillyard remarked at the end of his original description that this insect was nearer to the genus *Archescytina* than to the genotype, *Permoscytina kansasensis*, but he placed it in *Permoscytina* because it did not have the supposedly free Sc of *Archescytina* nor the curved R + M. However, as I have previously stated (1931, p. 114) R + M actually *was* curved in the type of *muiri* and it is now also apparent that *Archescytina* did not possess a free Sc. Obviously, then, *muiri* belongs to *Archescytina*, differing from the genotype (*permiana*) only by its size.

At present, therefore, there seem to be only four genera of Homoptera in the Elmo limestone, and these are separated mainly on the characteristics indicated in the following key:

1. R + M straight . . . . *Permoscytina* Till.
   R + M arched . . . . 2.
2. Free proximal piece of Cu1 much more than half as long as R + M . . . . *Archescytina* Till.
   Free proximal piece of Cu1 at most only half as long as R + M . . . . 3.
3. Cu1 forked . . . . *Permopsylla* Till.
   Cu1 unbranched . . . . *Paleoscytina* Carp.

With the following account of the Homoptera collected in 1935 I have included redescriptions of all the above genera except *Paleoscytina*, in order to clarify the generic characteristics.

Family ARCHESCYTINIDAE

Genus *Archescytina* Tillyard

Archescytina Tillyard, 1926, Amer. Journ. Sci., 11:385.

Tegmen: anterior margin straight or slightly concave, never convex; Sc close to R and R1 and weakly developed; R + M arched towards the anterior margin; Cu contiguous with M at the very base of the wing; free proximal part of Cu1 arched towards the posterior margin of the wing, joining M before it separates from R; Cu1 forked distally; two cross-veins, one (r-m) between M and Rs; the other (m-cu) between Cu1 and M3 + 4.

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[16] Tillyard states in his original description of this fossil that the course of Sc is not apparent at first, but can be seen if the lighting is properly arranged. However, even various arrangements of the illumination failed to reveal any trace of the free Sc described by Tillyard, although the other veins of the wing are preserved with striking clearness. Professor Dunbar, who examined the type specimen with me, has substantiated my conclusion.

Hind wing: very similar to the fore wing in shape and venation, except that the stem R + M is a little shorter, Cu1 is free from M for its entire length, and 2A is much reduced.

Body structure (known only in *A. permiana*): antennae slender, filiform, containing about 25 segments; beak well developed; tarsi three-segmented.

Genotype: *Archescytina permiana* Till.

Archescytina permiana Till.

Figure 15; plate 2, figure 1

Archescytina permiana Tillyard, 1926, Amer. Journ. Sci., (5) 11: 386; fig. 4.

Archescytina permiana Carpenter, 1931, Amer. Journ. Sci., (5) 22: 115; fig. 1.

Tegmen: length 8–8.5 mm.; width, 2.5–3.0 mm. Rs arising either half way between the origin of M and the fork of R1 (type) or slightly nearer to the latter; cell between Cu1a and Cu1b somwhat variable in shape, but always very large; Cu2 terminating at a point nearer to 1A than to Cu1b; 1A slightly curved sigmoidally.

Hind wing: length, 7 mm., width, 2.5 mm.; anterior margin shaped as in the fore wing; cell between Cu1a and Cu1b slightly narrower than in the fore wing; 1A sigmoidally curved; 2A very short and close to wing margin.

The body of this insect has already been described (Carpenter, 1931) and no additional details of structure have been observed since then.

In 1935 one excellent fore wing (3880ab) of this species was found in the upper layer of the limestone. This wing is complete and fully as well preserved as the type. In addition, one very fine specimen (3882) of the hind wing was collected in the upper layer. I have concluded that the latter belongs to *permiana* because it is the proper size and has the required venational characteristics. The strongly arched R + M eliminates it from *Permoscytina*, and its large size shows that it cannot belong to any of the species of *Permopsylla*. On the other hand it is much too small to be the hind wing of *Archescytina muiri* (Till.). *A. permiana* is therefore the only described species to which it can logically belong.

Archescytina muiri (Till.)

Figure 16

Permoscytina muiri Tillyard, 1926, Amer. Journ. Sci., (5) 11: 389.

Permoscytina muiri Carpenter, 1931, Amer. Journ. Sci., (5) 22: 118.

Tegmen: length, 11–12 mm., width, 4 mm.; costal space broad; Rs arising half way between the origin of M and the fork of R1; cell between Cu1a and Cu1b smaller than that of *permiana*. Cu2 terminating at a point nearer to 1A than to Cu1b; 1A smoothly curved at base, not sigmoidal in shape.

Nothing is known of the body structure or of the hind wing. There are no specimens of this species in the 1935 Harvard collection.

I have already given reasons above for transferring this species from *Permoscytina* to *Archescytina*. As Tillyard indicates in his figure of the type, the exact point of fusion of Cu1 with M is not clear, but the joining seems to take place just at the origin of M. The costal margin is shaped as in *permiana*, not arched as figured by Tillyard.

Genus *Permoscytina* Till.

Permoscytina Tillyard, 1926, Amer. Journ. Sci., (5) 11: 387.

Tegmen: slightly convex, very nearly straight, but not concave; Sc close to R1, well developed; R + M straight, not arched towards the anterior margin; Cu apparently free from M at base of wing; free proximal part of Cu1 nearly parallel with R + M, joining M after the latter has separated from R; Cu1 forked distally; two cross-veins, r-m and m-cu, distributed as in *Archescytina*.

Hind wing: very similar to the fore wing, with no obvious differences except that Cu1 is free from M for its entire length. The basal portion of the hind wing is unknown, but 2A is presumably reduced as in the hind wing of the other genera of archescytinids.

Body structure: only the general form of the thorax and abdomen is known. This will be described below.

Permoscytina kansasensis Till.

Figure 17; Plate 1, figure 3.

Permoscytina kansasensis Tillyard, 1926, Amer. Journ. Sci., 11: 388.

Permoscytina kansasensis Carpenter, 1931, Amer. Journ. Sci., 22: 117.

Tegmen: length, 11–12 mm.; width, 3.5 mm. Costal space narrow; pterostigma long and slender; Rs arising at a point much nearer to the pterostigma than to the origin of M; cell between Cu1a and Cu1b about as large as in *A. muiri;* Cu2 probably terminating at a point midway between Cu1b and 1A. 1A is smoothly curved and both it and 2A are exceedingly strong veins.

One specimen (No. 3881ab) of this species was collected in 1935; it consists of a nearly whole specimen, in dorsal aspect, but unfortunately the head is not preserved. Although the fore wings lie over the hind wings, it is nevertheless possible to distinguish quite easily the veins of each of the wings. Since this is the only specimen of an archescytinid that has been found in which both hind and fore wings are present, it is an exceedingly interesting fossil (Fig. 17). It is this specimen that proves conclusively that Cu is entirely free from M in the hind wing of the archescytinids. Cu1 is easily seen in the fore and hind wings of the right side of the specimen and because of the superimposition of the wings, it can be readily observed that in one wing (fore) Cu1 joins M, whereas in the other wing Cu1 runs directly from the base to the margin. Apparently the other veins are even more alike in the two pairs of wings than is the case in *Archescytina;* at any rate, the veins of both wings seem to coincide throughout, except in the apical region. The posterior and apical margins of the hind wing are not clearly indicated, but presumably the hind wing was somewhat shorter than the fore and more narrowed proximally.

The body of this specimen is not very well preserved for the most part. It is possible to distinguish a broad thorax, 3 mm. long and 4 mm. wide, and a short abdomen, 5 mm. long and 3 mm. wide. The wings were therefore twice as long as the abdomen, and must have extended far beyond the end of the latter when the insect was at rest. Only one segment, the femur, of any of the legs is preserved; the position of this indicates clearly that it is a fore leg. This femur is swollen like that of *A. permiana* (Carpenter, 1931c, fig. 1).

The most striking and extraordinary structure which this fossil shows is a long processes, that extends straight back from the end of the abdomen. This is 9 mm. in length and is therefore longer than the thorax and abdomen combined. When I first examined the fossil only a small piece of this structure was visible and I surmised that it was an ovipositor; but after its full length was apparent its nature became more puzzling. It is perfectly obvious that it is not one of a pair of cerci and that it does not consist of the two cerci lying close together, for it is not segmented and has none of the other characteristics of cerci. There are but two interpretations of this structure that seem at all possible. One is that it is an ovipositor. It is much too long in proportion to the size of the insect, however, to enable us to conceive its use in oviposition. Of course if we assume that it was capable of being arched or coiled, such a function would be more easily imagined; but its appearance is decidedly against that assumption. The fact that it is preserved in a perfectly straight line strongly indicates that it was not flexible, as are the long ovipositors of the parasitic Hymenoptera. Furthermore, if this terminal structure were an ovipositor, it would necessarily represent either the paired first valvulae or paired second valvulae; in which case of course there ought to be some indication of the corresponding pair. Since there is not, we are justified, I think, in concluding that the evidence is decidedly opposed to its being an ovipositor.

The only other interpretation which seems possible is that it is a respiratory tube, similar to that in Recent members of the hemipterous family Nepidae. This view is perfectly consistent with the straight and rigid appearance of the terminal process in the fossil, and especially with its median longitudinal division, for of course the respiratory tube of the Nepidae is formed by the application of a pair of grooved processes. A comparison of the respiratory tube of the nepids and the terminal process of the fossil reveals such striking similarities of formation, that I believe we are justified in attributing a similar function to the structure in the fossil.[16a]

This conclusion, of course, presupposes that the insect was aquatic. So far as known at present, there is no indication of modification of the rest of the body for an aquatic environment. Both pairs of wings are broad and their nature is hardly consistent with what we should expect in an aquatic species. It seems likely, therefore, that these insects were aquatic in their nymphal stages, before the wings were fully developed; and that the adults, although retaining the respiratory tube, were terrestrial and capable of active flight. In this connection it should be noted that, apart from the modification of the respiratory system, the nepids are not adapted to an aquatic existence, their fore legs being rapto-

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[16a] It should perhaps be pointed out that this process can not be part of the beak because the latter is known to be much too short in the Archescytinidae to extend even to the tip of the abdomen; and because the origin of the process from the abdomen is very clear in the fossil.

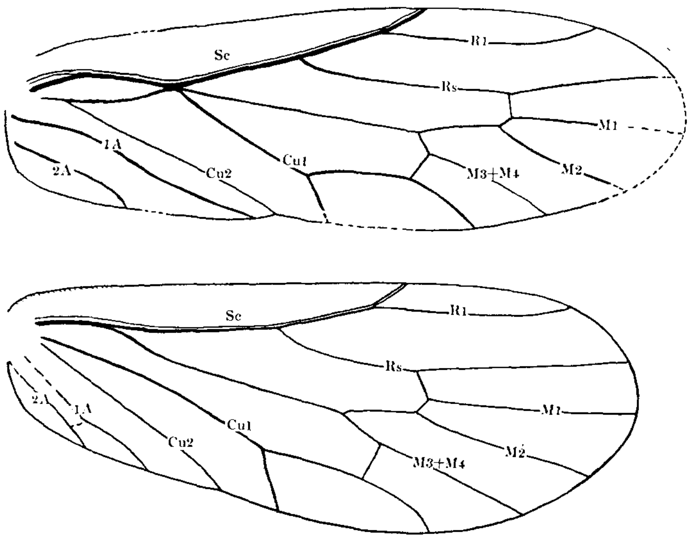
Sc
R1
Rs
M1
M2
M3+M4
Cu1
Cu2
1A
2A

FIGURE 15. *Archescytina permiana* Till.; fore wing drawn from holotype, No. 5111, Peabody Museum, Yale University; hind wing drawn from specimen No. 3882, Museum of Comparative Zoölogy.

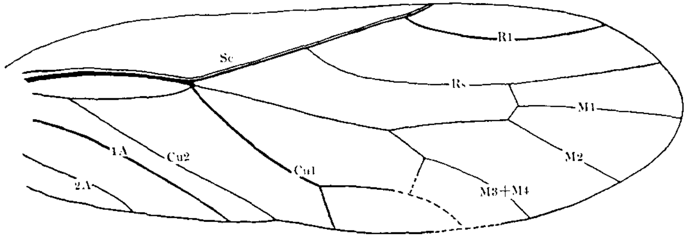
Sc
R1
Rs
M1
M2
M3+M4
Cu1
Cu2
1A
2A

FIGURE 16. *Archescytina muiri* (Till.), fore wing, drawn from holotype, No. 5113, Peabody Museum, Yale University.

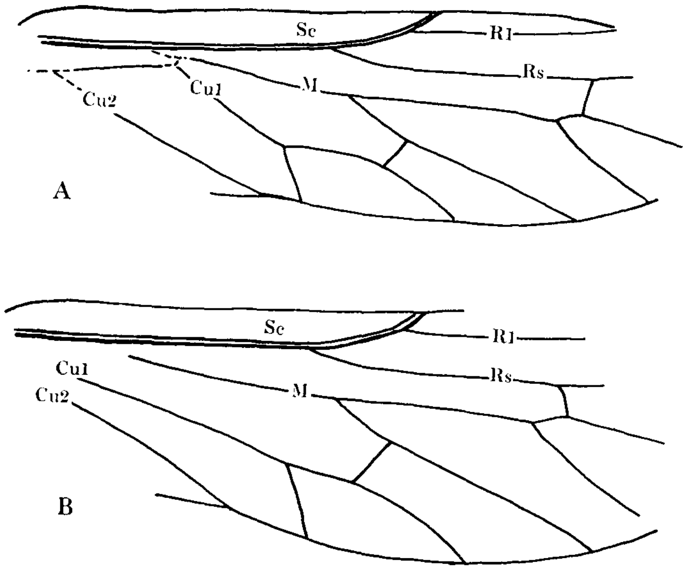
Sc
R1
Rs
M
Cu1
Cu2
A
B

FIGURE 17. *Permoscytina kansasensis* Till., drawing of fore and hind wing; specimen No. 3881ab, Museum of Comparative Zoölogy.

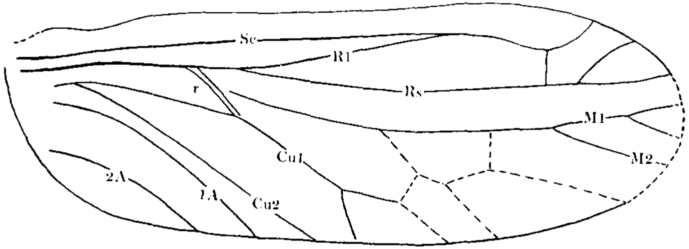
Sc
R1
Rs
r
M1
M2
Cu1
Cu2
1A
2A

FIGURE 18. *Lithopsocidium permianum* Carp., drawing of venation, specimen No. 4322ab, Museum of Comparative Zoölogy.

rial and the others cursorial. We know nothing, unfortunately of the meso- and metathoracic legs of *Permoscytina kansasensis*, but in the very closely related *Archescytina permiana*, the middle and hind legs were fitted for walking, and the fore legs were raptorial. The latter assertion is based upon the fact that the fore tarsi terminated in a single stout claw (Carpenter, 1931c, fig. 1), and the femur was much swollen, and possessed a row of stout spines along the outer margin. All we know of the fore leg of *Permoscytina kansasensis* is the femur which is preserved in the specimen under discussion (3881); but, as previously mentioned, that is swollen as it is in *A. permiana*. I believe therefore the available evidence indicates that *Permoscytina* was an aquatic insect at least in the nymphal stages, breathing by means of a respiratory tube like that of the Nepidae, and feeding on prey which it captured by means of the raptorial fore legs. Also, although we have not yet found any specimens of *Archescytina* which show a respiratory tube, I believe that the members of this genus were likewise aquatic, since the two genera were obviously very closely related, and *A. permiana* also had raptorial fore legs.

The foregoing discussion does not intend to imply a close phylogenetical relationship between the hemipterous (heteropterous) family Nepidae and the homopterous genus *Permoscytina*. That such a relationship has not existed is perfectly obvious. The significant fact (assuming the above interpretation is correct) is that in the Lower Permian an abdominal respiratory tube was developed in the Homoptera which apparently served the same purpose as that which now occurs in the Nepidae. The presence of this structure is another instance of the parallel evolution which has taken place so frequently in unrelated families of insects.

Genus *Permopsylla* Till.

Permopsylla Tillyard, 1926, Amer. Journ. Sci., (5) 11: 390.

Permopsylla Carpenter, 1931, Amer. Journ. Sci., (5) 22: 119.

Tegmen: anterior margin slightly concave opposite origin of M, sometimes almost straight, but never convex; Sc close to R + M and R1, weakly formed; R + M arched towards anterior margin; free proximal piece of Cu1 straight, directed anteriorly, fusing with M close to its origin. Cu2 forked; 1A nearly straight; 2A generally curved sigmoidally.

The hind wing of this genus is apparently like that of *Archescytina*. One of the 1935 specimens of *Permopsylla minuta* Carp. (No. 3878ab) has a part of the hind wing preserved, and shows that Cu1 is entirely independent of M. The species which I previously described (1931) as *Lithoscytina cubitalis* is obviously a hind wing of some species of *Permopsylla*, presumably *P. grandis* Carp. This specimen shows the characteristic cubitus of the hind wing. It also shows a relatively straight R (or R + M), and this same peculiarity is even more clearly indicated in the specimen of *minuta* mentioned above.[17] 2A is very close to the hind margin, as in the hind wings of the other genera of Archescytinidae.

Almost nothing is known of the body structure of these insects, their small size greatly reducing the chances of good preservation. The new specimen of *P. minuta* mentioned above (No. 3878) is the only one so far found which shows any of the body and no details are discernible. The entire body is only 2 mm. long, with a maximum width of .8 mm. Since the wings are about 2.5 mm. long they obviously extended beyond the end of the abdomen in the position of rest. There appears to be a terminal process extending from the abdomen, but its form is very obscure.

Twenty-three specimens belonging to this genus were secured in 1935; all but three of these were found in the upper layer of the limestone, confirming my earlier statement that the order Homoptera is probably more abundantly represented in the upper layer than the lower. *P. americana* Till. is represented by seven good fore wings, two being from the lower layer. Two of the wings are especially well preserved (No. 3860ab, 3861ab). Eight specimens, all from the upper layer belong to *P. permiana* Carp., two of the lot (No. 3878ab, 3875ab) being excellently preserved. The largest species of the genus, *grandis*, is represented by four fossils consisting of fore wings, all from the upper layer; three of these (Nos. 3867ab, 3869ab, and 3770ab) are splendidly preserved. The smallest species, *minuta*, includes two fine specimens; one (No. 3877ab) is a fore wing from the upper layer, and the other (No. 3878ab, lower layer) is the more nearly complete specimen already mentioned, showing a fore wing, part of a hind wing, and the body.

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[17] The proximal portion of R is probably even more nearly straight in the hind wing described as *Lithoscytina* than it is represented in my figure (1931c, fig. 9). That part of the wing was not very clearly preserved, and since the new specimen of *minuta* has the proximal part of R almost exactly straight, the same was probably true of the former hind wing.

THE AFFINITIES OF THE ARCHESCYTINIDAE

In addition to the foregoing Lower Permian species, the family Archescytinidae also includes several described by Martynov (1933) from the upper Permian of Russia. Certain changes must now be made in the generic disposition of Martynov's species, however, to conform with the corrections noted above in the genotypes of *Archescytina* and *Permoscytina*. *Permoscytina sojanensis* Martynov and *P. tetraclada* Martynov obviously do not belong to *Permoscytina*, since the stem R + M is strongly arched. As Martynov mentioned, both of these species were very close to *muiri* Till., rather than to the genotype of *Permoscytina*, i. e., *kansasensis*. The removal of *muiri* to *Archescytina* must therefore be followed by the transfer of both *sojanensis* and *tetraclada* to *Archescytina*. The genus *Sojanoscytina* Martynov is clearly close to *Archescytina*, rather than to *Permoscytina*, but remains a distinct genus on the basis of the structure of the anal veins as well as the media. However, the hind wing which Martynov describes as *Sojanoscytina* (?) *latipennis* can hardly belong to any member of the family Archescytinidae, since it has Cu1 joined to M as in the fore wings. If it should turn out that the species of *Sojanescytina* actually did possess such a hind wing as he describes as *latipennis*, then the genus will require a new family for its reception. The free Cu1 now known to have existed in *Archescytina*, *Permoscytina*, and *Permopsylla*, indicates a very different line of evolution from that depicted by the fused Cu1 in *S.* (?) *latipennis*.

In 1931 I pointed out that the Archescytinidae appeared to possess certain characteristics which eliminated them from both the existing divisions (Sternorrhyncha and Auchenorrhyncha) of the Homoptera and I therefore established for them the division Paleorrhyncha. Martynov, however, believes (1933) that the archescytinids are nevertheless closer to the Sternorrhyncha than to the Auchenorrhyncha. He concedes that the 3-segmented tarsi of the Archescytinidae excludes them from the Sternorrhyncha, but expands the definition of the Sternorrhycha to include Homoptera with 3-segmented tarsi in order to embrace the Archescytinidae. It is of course purely an arbitrary matter in these cases whether one prefers to modify the conception of an existing category to include such extinct groups or to establish a parallel category especially for them. The choice in the matter presumably depends upon the amount of modification that may be necessary, and there can be no hard and fast lines drawn between the two procedures. In the case of the Archescytinidae I personally prefer to regard them as members of a distinct division, rather than to modify our conception of the Sternorrhyncha in order to include them there.

Martynov's conclusion that the archescytinids stand very close to the true Sternorrhyncha (especially the Aphidoidea) now appears hardly justifiable. His assumption that the isolated hind wing described as *Sojanoscytina* (?) *latipennis* belonged to the Archescytinidae seems to be quite incorrect, in view of the nature of the hind wings found attached to the new specimens described above from the Elmo limestone. The discovery that *Permoscytina* (and presumably all the Archescytinidae) were aquatic at least as nymphs, possessing an abdominal respiratory tube, shows also that this particular family was not ancestral to either of the existing divisions of the Homoptera. However, it is obvious that this modification was only an adaption to an aquatic existence, and that their fundamental characteristics (such as the 3-segmented tarsi, the complete clavus, and the multisegmented antennae) were not concerned with their aquatic specializations. An homopteron possessing such fundamental features, but not specialized for an aquatic life, would be a more typical member of the division Paleorrhyncha and might conceivably be in the common ancestral line of both existing divisions.

After the manuscript of the present paper had been completed, I received a recent publication by G. Zalessky (1937), in which the author establishes the Order Hemipsocoptera for a new fossil, *Maueria sylvensis* Zal., from the Permian of Russia. This specimen, although not very well preserved, consists of a nearly complete insect, the wings being outstretched and the body faintly indicated. As is apparent from the name of the new order, Zalessky considers the fossil to represent an order intermediate between the Psocoptera and the Hemiptera. It is at once obvious, however, even from an examination of Zalessky's diagrammatic figures of the wings, *that the fossil is a typical archescytinid, undoubtedly belonging to* Archescytina *itself or one of the other genera of the family which have already been found in the*

Russian Permian! Zalessky was led to attribute psocopterous affinities to this fossil because of the hind wing, which has Cu1 free, as it is now known to be in the archescytinids. The family Maueriidae is obviously a synonym of Archescytinidae and the genus *Maueria* is here placed as a synonym of *Archescytina.* The incomplete preservation of the wings of the fossil makes the exact course of the veins obscure, so that the specific characteristics are necessarily uncertain. It is very unfortunate that Zalessky should have erected a new order for a unique and poorly preserved specimen, especially since he had previously established another invalid order (Permodonata) on equally insufficient material. A new order of fossil insects, as Tillyard has pointed out (1931, p. 232), should be avoided as far as possible, and not be made as soon as the slightest pretext is offered. The body structure of the Archescytinidae (Maueriidae) shows beyond question that they were true Hemiptera, even though the hind wings contained some suggestions of the Psocoptera.

Order PSOCOPTERA

194 specimens of Psocoptera were collected in 1935, bringing the total number of these insects in the Museum of Comparative Zoölogy to 487. Only seventy of the new fossils were found in the lower layer. In addition to the species discussed more fully below, *Dichentomum latum* Carp., *D. grande* Carp., and *Progonopsocus permianus* Till. are represented in the new material, the first by six specimens (five upper, one lower layer); the second by five (three upper, two lower layer); and the third by four (two upper, two lower layer).

Family DICHENTOMIDAE

In a very recent paper (1937) Zalessky discusses in some detail the classification of the Psocoptera of the Elmo limestone and takes issue with me on the synonymy and classification of certain species. In the first place he believes that the family name Psocidiidae should be employed instead of Dichentomidae. The family Psocidiidae was established by Tillyard in 1926 for six genera in the Elmo limestone, which he described in the following order: *Dichentomum* (p. 320), *Psocidium* (p. 321), *Chaetopsocidium, Metapsocidium, Pentapsocidium* and *Permentomum.* A study of Tillyard's types of the species belonging to these genera, as well as a great many more specimens, led me to conclude (1932, pp. 3–6) that the five latter genera (*Psocidium, Chaetopsocidium, Metapsocidium, Pentapsocidium, Permentomum*) were synonyms of *Dichentomum.* The family name was of course changed to Dichentomidae, since *Psocidium* was a synonym of *Dichentomum.* Now Zalessky, although admitting that the foregoing genera are synonymous, makes the extraordinary statement (p. 70) that in uniting these genera the generic name *Psocidium* should be used, thus retaining the family name Psocidiidae. Such a procedure would of course be contrary to the rules of priority of names,[18] and I am utterly unable to understand how Zalessky could make such a proposition unless he is totally unaware of the existence of such rules. Tillyard himself in a later paper (1935, p. 267) accepts the synonymy of *Psocidium* with *Dichentomum* and of course states that the family name should be Dichentomidae.

Although Zalessky agrees with my synonymy of Tillyard's genera of the Elmo Psocoptera, he rejects my synonymy of the species. Unfortunately, he has completely failed to note that many of the species concerned (*Chaetopsocidium sellardsi, Metapsocidium loxonerum,* etc.) *were incorrectly described or figured by Tillyard,* as I pointed out in detail (1932, pp. 4–6). He has obviously not taken into account my correction of the descriptions of these species in his attempt to classify the Elmo Psocoptera; this is well shown by the fact that he illustrates his paper with copies of two of Tillyard's figures (*Psocidium permianum* and *P. kansasense*) without mentioning my corrections of them (1932, pp. 8–9). It is this same oversight on Zalessky's part which leads him to ask why *D. latum* Carp. is not a synonym of *D. tinctum,* inasmuch as the various species which Tillyard described and which I regarded synonyms of *tinctum* show so much diversity of venation. The simple fact, of course, is that Tillyard's species do not have the diversity that was attributed to them, but show differences which are trivial and occur in the right and left wings of the same individual! But in the course of my examination of more than four hundred specimens of *Dichentomum* I have found none intermediate in structure between *tinctum* and *latum.* It is unfortunate that Zalessky undertook to revise the synonymy of the Psocoptera in the Elmo limestone, especially since he has never seen a single specimen from the formation.

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[18] International rules of Zoological Nomenclature, articles 25 and 28.

Dichentomum tinctum Till.

Plate 2, figure 6

Dichentomum tinctum Tillyard, 1926, Amer. Jour. Sci., (5) 11: 320.
Dichentomum tinctum Carpenter, 1932, ibid., 27: 70 (complete synonymy given here).
Dichentomum tinctum Carpenter, 1933, Proc. Amer. Acad. Arts Sciences, 68: 443.

164 specimens of this insect were collected in 1935, more than on any previous trip. The total number of specimens of this species now contained in the Museum of Comparative Zoölogy is about 390. Most of the new fossils are of course isolated fore or hind wings and need no further comment; but a few are especially interesting because of the body structures preserved. Five of the specimens (4328ab, 4329ab, 4330ab, 4331ab, 4334ab) show clearly the rostrum, which I have previously described in this species. One specimen (No. 4332ab), preserved in lateral view with one of the wings outstretched, is of even greater interest because genital structures are distinctly visible. These appendages, which are .6 mm. long apparently consist of a pair of curved hooks (Plate 2, figure 6), and are presumably homologous with the copulatory hooks occurring in the males of some Recent psocids (cf. Plate I, figs. 5, 6 of Enderlein's "Copeognatha" of Collections Selys, Fasc. III (2), 1919). The apparent absence of the hooks in the specimens of *D. tinctum* previously studied is undoubtedly the result of their failure to be preserved. Because of the small size of these insects optimum preservation is necessary to show such details.

Lithopsocidium permianum Carp.

Figure 18

Lithopsocidium permianum Carp., 1932, Amer. Journ. Sci., 24: 14; fig. 7. 1933, Proc. Amer. Acad. Arts Sci., 68: 449, fig. 15.

A third specimen (No. 4322ab) of this rare insect was collected in the upper layer of the limestone in 1935. Like the others, this one consists of a single wing, and is not very well preserved; but it is of much interest because the area around the origin of M is much clearer than in the other two specimens, and shows distinctly a certain peculiarity not previously described. The stem of R in all three fossils is strongly convex, and in the new specimen there is a similar strongly convex ridge leading from R, at a point slightly proximal of the origin of Rs, to Cu1 (figure 18). An examination of the other two specimens of *L. permianum*, including the type, shows that a similar oblique ridge is likewise present in them, but presumably because of the poor preservation of that area of the wings, they were not considered as part of the wing when I described them. The new fossil clearly demonstrates that the ridge is a definite structure in the wing. I am at a loss to explain its nature. In none of the specimens is this ridge preserved as a dark line as are the veins in the wing; it is the same color as the membrane. Also there is no vein in the wings of the other Psocoptera with which it might be considered homologous. The relationship between the ridge and the base of the media is obscure. In none of the specimens of *permianum* is the origin of the media clear, but this is likewise true of the other Permian Psocoptera, even *Dichentomum tinctum*, of which a great many specimens have been collected. Whatever the nature of this ridge may be, it is undoubtedly a constant feature of the wing and should be added to the generic characteristics.

The new specimen of *permianum* substantiates the conclusion that the costal margin is curiously curved and unlike that of the other Permian Psocoptera. The costal area of the new fossil is not well preserved and the several cross-veins, previously noted in another specimen, are not visible. In my previous discussions of *Lithopsocidium*, I have assumed from the shape of the wing that the specimens were hind wings; this also applies to the new specimen, but the differences in the fore and hind wings of the other Permian Psocoptera are so slight that this is hardly more than an assumption.

Family PERMOPSOCIDAE

Permopsocus latipennis Tillyard

Plate 2, figure 5

Permopsocus latipennis Tillyard, 1926, Amer. Journ. Sci., (5) 11: 340. Carpenter, 1932, ibid., 24: 13 (complete synonymy given here).

Five specimens of this species were collected in 1935, all except one in the upper layer of the limestone. Only one of these deserves comment (No. 3992ab). This consists of a more or less complete specimen preserved in lateral aspect with two wings outstretched. The interesting feature of this fossil is the presence of a conspicuous process at the end of the abdomen (plate 2, fig. 5). This apparently arises from the region of the ninth sternite and is 1 mm. long. Although in its general appearance it resembles an ovipositor, I believe that it represents one of a pair of male copulatory appendages, homologous with the hooks just described in *D. tinctum.* This conclusion has been reached because not only is the process bluntly rounded distally, but it has the false joint near its middle characteristic of the male copulatory structures (e.g., styli of male Plectoptera), and apparently also has the false terminal segments. The presence of such copulatory processes in *Permopsocus* would not be unexpected in view of their existence in *Dichentomum.*

Permopsocus ovatus, new species

Figure 19

Fore wing: proportionally broader than in *P. latipennis;* length, 4.5 mm.; width, 1.8 mm. Sc with only slight bend at the base, as in *P. latipennis;* costal space broad, much more so than in *P. latipennis* and closer to R1 than in the latter; ir1 strongly oblique, ir2 slightly inclined; two cross-veins are present (in the type specimen) between Rs and M, but as in the case of *P. latipennis*, their presence is probably an individual characteristic only; areola postica very large, wider than high; 2A apparently longer than in *P. latipennis.*

Holotype: No. 4336ab, Museum of Comparative Zoölogy; collected by the writer in the upper layer of the Elmo limestone, 1935.

This species, although close to *latipennis*, differs chiefly in the much larger and wider areola postica and in the proportionally broader, suboval wing. The shape of the wing might, by itself, be regarded as an individual characteristic, but the large areola postica cannot be so considered, especially since specimens of *latipennis* present very little variation in the shape of this cell. The presence of the chitinous lobe at the base of the posterior margin shows that the type of *ovatus* is a fore wing.

Family CYPHONEURIDAE

In 1932 I described two very small and remarkable wings from the Elmo locality as *Cyphoneura permiana* and *C. reducta*, placing the genus close to *Lophioneura* Till. from the Upper Permian of Australia. The latter genus had been assigned to the Homoptera by Tillyard, who believed that the family it represented (Lophioneuridae) was directly ancestral to the Chermidae (Psyllidae). I accordingly assigned the family Cyphyoneuridae to the Homoptera, although I noted that the venation of these wings contained many suggestions of that of the Psocoptera.

More recently (1935) Tillyard has studied and described a number of other specimens from the Australian Permian related to *Lophioneura* and *Cyphoneura,* and concludes from the body structure preserved with the additional wings that the insects were Psocoptera, not Homoptera. If Tillyard's figures correctly depict the head structure of these insects, there can be no doubt of the psocopterous affinities of the fossils, and I accept Tillyard's conclusion with that assumption. I do not, however, agree with Tillyard on the classification of these peculiar insects. He maintains that all of the Psocoptera possessing "a sigmoid Cu1 and abnormal origins of Rs, M and Cu2" should be placed together in the family Lophioneuridae, thus eliminating the family Cyphoneuridae. On this basis, however, one of the Kansas species, *C. reducta*, which possesses a perfectly straight Cu1, is eliminated from the Lophioneuridae, although Tillyard placed it there. Furthermore, the expression, "abnormal origins of Rs, M and Cu1," is too vaguely inclusive to be of any aid in classifying these insects. Much more significant, in my opinion, is the fact that the species of *Lophioneura* (*ustulata* and *angusta*) differ strikingly from those of all other genera of Psocoptera by the complete absence of Cu2 as an independent vein. Such a marked difference certainly seems to require family distinction, the Cyphoneuridae including those species with Cu2 present as a free vein, and the Lophoneuridae, those species lacking Cu2. On this basis *Cyphoneura, Astrocypha,* and *Lophocypha* are here placed in the family Cyphoneuridae; and *Lophioneura* in the family Lophioneuridae.

Family DELOPTERIDAE

Only fourteen species of this family were collected in 1935. This small number of specimens is undoubtedly due to the fact that most of the collecting was done in the upper layer of limestone, in which the Delopteridae are much less common than they are in the lower layer. Of this series of specimens only one (*Delopterum latum* Till. No. 3989) was found in the lower layer.

Delopterum minutum Till. is represented by two specimens.[18a] No. 3978 is a complete and well preserved fore wing; No. 3979 is a complete specimen, in dorsal view, showing the wings outspread and the body very well, although no legs are visible. This fossil has the abdomen better preserved than any other specimen that has been collected, and it is especially interesting because it shows a pair of small but distinct cerci (Plate 2, fig. 3).

[18a] Since *Pseudomantis* Martynov is a synonym of *Delopterum* (Carpenter, 1933, p. 452), it is necessary to designate a new name for *Ps. minuta* Mart. (Permian of

In neither of the new specimens am I able to make out the oblique vein between R1 and R2 + 3, which is present in at least some specimens previously collected and studied. The presence or absence of this vein may be a matter of individual variation rather than of specific nature, unless of course very fine preservation is needed to show it.

Delopterum elongatum Sell. is represented in the new material by 11 specimens (No. 3979–3988), which is about twice as many individuals as have previously been known. Nearly all of these are isolated fore wings and deserve no further comment. It should be noted that some of these wings are only a little over 5 mm. long, which is very near to the maximum size of *minutum*. The length of the subcosta seems to be variable, though it is usually longer in *elongatum* than it is in *minutum*. The occurrence of so many specimens of *elongatum* substantiates the tentative conclusion based on the 1932 material, that this species is much commoner in the upper layer than in the lower layer of the limestone.

Delopterum latum Sell. (figure 20) is represented by a single, well preserved wing from the lower layer (No. 3889). In all probability this species does not occur in the upper layer; at any rate no specimens of it have been found there so far. While there is a possibility that *minutum* and *elongatum* are synonyms, *latum* is very readily distinguished by the sigmoidal form of 2A and its branch leading to the hind margin.[19] In this species also the forking of M takes place much nearer its origin than it does in the other species, and as a consequence the anterior branch, M1 + M2, is very close to Rs proximally. As a matter of fact the actual basal connection of M1 + M2 is not discernible in any of the specimens which have been collected and it may be that this part of the vein has been atrophied or arises from Rs.

Delopterum kansanum, new species

Figure 21

Fore wing: length 6 mm.; width, 1.8 mm. Costal margin distinctly convex, with a slight concavity near the base of the wing; Sc remote from anterior margin and long, extending far beyond the middle of the wing and nearly to the end of R1; M arising from Cu1 a little proximad of the origin of Rs; M dividing close to its origin as in *latum*, but with M1 + M2 remote from Rs; areola postica lanceolate, Cu1 forking dichotomously; 2A sigmoidally curved, as in *latum*, but longer.

Holotype: No 3990ab, Museum of Comparative Zoölogy; collected by the writer in the upper layer of the Elmo limestone (1935). The type specimen consists of a complete and very well preserved fore wing.

This species is close to *latum*, but differs primarily by the longer Sc, the much broader costal area, the remoteness of M1 + 2 from Rs, the lanceolate areola postica and the longer 2A. It may be that some of these characteristics, such as the form of the areola postica, will turn out to be individual ones; but others, such as the length of Sc and the width of the costal area, can hardly belong in this category.

The affinities of the family Delopteridae are still uncertain. In my previous paper I reviewed the evidence bearing on this subject, and have shown that it indicates a close relationship with the Psocoptera, as originally concluded by Tillyard. Unfortunately, we have very little knowledge of the head structure, aside from the fact that a rostrum, like that of the Dichentomidae, was not present.

Order PROTELYTROPTERA

Thirty-three specimens of Protelytroptera were found in 1935, making a total of eighty-nine in the Museum of Comparative Zoölogy. The new fossils contribute materially to our knowledge of the structure of the elytra, especially in the obscure family Blattelytridae.

Tikhie Gory, Russia) that specific name having been used for the genotype of *Delopterum*. I brought this to Dr. Martynov's attention in 1937 and he wrote in November of that year that he would propose the name *kamense*. Since he died a few weeks later without being able to prepare a note for publication, I take this opportunity to make that designation: *Delopterum kamense*, n. n., for *Delopterum* (*Pseudomantis*) *minutum* Martynov (1928), nec *D. minutum* Sellards (1909).

[19] Martynov has placed *latum* in a separate genus, *Pseudodelopterum* (1928, p. 66, foot-note), but I do not believe there are enough differences between this species and the foregoing to justify generic separation.

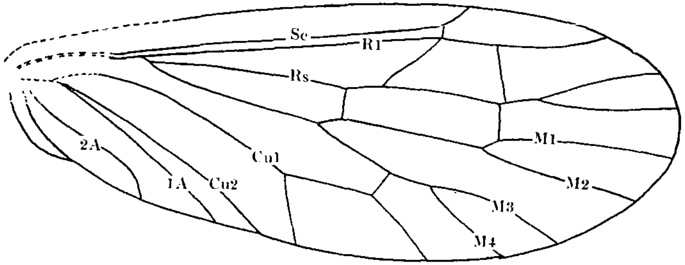
Sc
R1
Rs
M1
M2
M3
M4
Cu1
Cu2
1A
2A

Figure 19. *Permopsocus ovatus* n. sp., drawing of fore wing; holotype, No. 4336ab, Museum of Comparative Zoölogy.

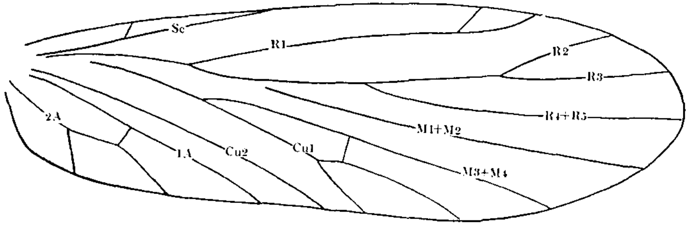
Sc
R1
R2
R3
R4+R5
M1+M2
M3+M4
Cu1
Cu2
1A
2A

Figure 20. *Delopterum latum* Sell., drawing of fore wing; specimen No. 3889, Museum of Comparative Zoölogy.

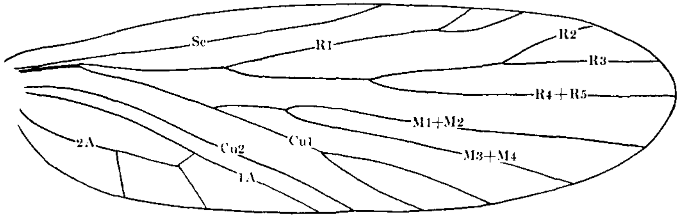
Sc
R1
R2
R3
R4+R5
M1+M2
M3+M4
Cu1
Cu2
1A
2A

Figure 21. *Delopterum kansanum*, n. sp., drawing of fore wing; holotype, No. 3990, Museum of Comparative Zoölogy.

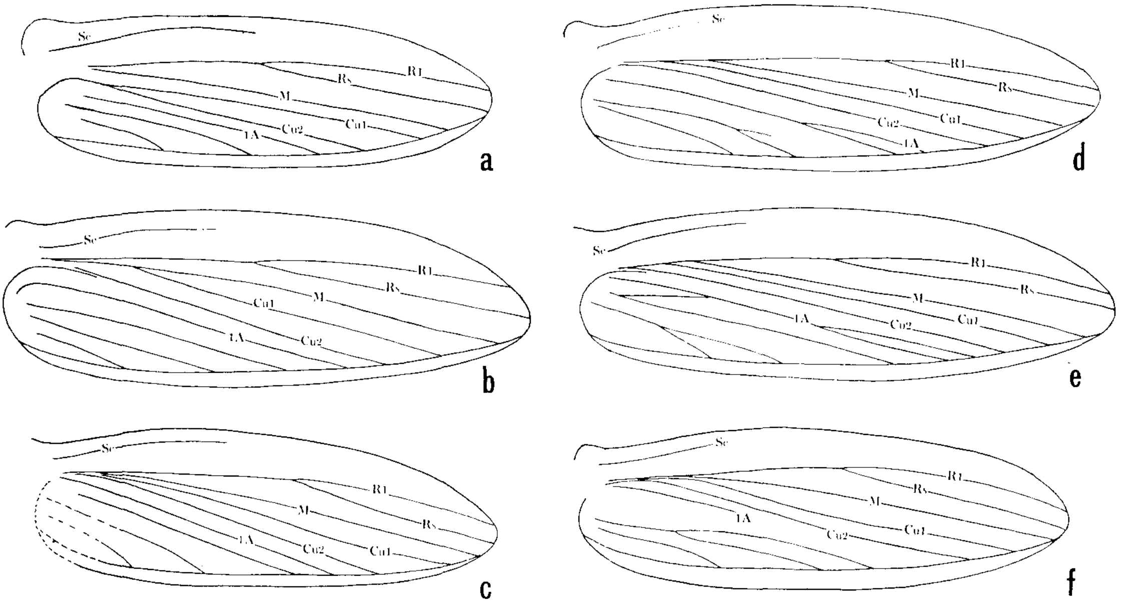

FIGURE 22. *Protelytron permianum* Till., venation of elytra; a, specimen No. 3266; b, No. 3889; c, No. 3893; d, No. 3884; e, No. 3883; f, No. 3892.

Family PROTELYTRIDAE

Genus *Protelytron* Till.

Protelytron Tillyard, 1931, Amer. Journ. Sci., (5) 21: 239.
Protelytron Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 465.

Protelytron permianum Till.

Figure 22

Protelytron permianum Tillyard, 1931, Amer. Journ. Sci., (5) 21: 240; figs. 1–3, 14, 15.
Protelytron permianum Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 467; figs. 17, 18.
Protelytron tillyardi Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 473, fig. 19.

In the new material there are ten specimens belonging to this species, five of which have a venation in the elytra which is typical of the species (Carpenter, 1933, fig. 17): Nos. 3886, 3887, 3888, 3890, 3891 (all from the upper layer except the last). The venation of the other five specimens, however, is not like that which has previously been recognized in *permianum*, the differences being mainly in the branches of M and Cu. In the typical elytra of *permianum* (figure 22a) M is free from R for its entire length, arising near the base of the elytron; similarly, Cu arises independently, and gives rise to Cu1 and Cu2 at the very base of the elytron. Cu2 coincides or very nearly coincides with the *vena dividens*, which is clearly indicated proximally. In the first of the atypical elytra mentioned (figure 22b, No. 3889, lower layer) the venation differs from the foregoing in that Cu1 is coalesced with the proximal part of M, so that M appears to be deeply forked. In the second elytron (figure 22c, No. 3893, upper layer), R, M and Cu are all coalesced proximally, and all arise independently from this common stem. In the third elytron (figure 22d, No. 3884, upper layer), Cu1 is coalesced with M as in b above, but M is also fused proximally with R. In the fourth elytron (figure 22e, No. 3883, upper layer), the structure is exactly as in d, except that Cu2 is slightly coalesced with the stem of R also. In the fifth elytron (figure 22f, No. 3892, upper layer), Cu1 is free from M, but M is coalesced with R.

It is apparent from our examination of these elytra that the structure of R, M, Cu1 and Cu2 is subject to much individual variation, comparable to a certain extent to the variation which occurs in the family Lemmatophoridae (Order Protoperlaria). There seems to be no justification for regarding these differences as of a specific nature, because they show so many intermediate conditions. If our study of the venation of these elytra is extended to include other species and genera, it also becomes apparent that the evolution within the family Protelytridae has largely been concerned with changes in the proximal structure of R, M, and Cu. The starting point of this evolution seems to be represented by the typical venation of *permianum*. From this point there seem to have been two lines of evolution. One of these, represented in *permianum*, is exemplified by the tendency for M and Cu to coalesce with R. The other line, represented in *Protelytron furcatum* n. sp. (figure 23a) is in the direction of the coalescence of Cu1 and Cu2 for a considerable distance from the base of the elytron. This line reaches its extreme development in *Permelytropsis*, in which Cu1 and Cu2 have entirely coalesced (Carpenter, 1933, fig. 21).

To return to the elytra of *permianum* shown in figure 22, it should be noted that there is considerable variation in the structure of the anal veins. A fourth anal vein is present in some of the elytra, but this is often very feebly developed. There is also a tendency for the anal veins to be forked, as in d and e, figure 22. These forkings seem to occur in a haphazard manner, indicating that they are mere individual fluctuations. The condition of the anal veins in the specimen shown in figure 22f is decidedly different from that of any of the other elytra which I have seen; but it should be noted that the structure of 1A in this fossil is strongly suggestive of abnormal conditions. Since similar variations (exclusive of the last) are to be found in the elytra of *permianum* which are otherwise typical of the species, I am led to conclude that we have here but another instance of the unusual amount of individual variability of the Permian insects to which I have previously referred.

These new specimens of *permianum* indicate that there is also considerable variation in the shape of the elytron and the width of the sutural margin. I am therefore of the opinion that *P. tillyardi* Carp., which was based on an unusually broad elytron with a very wide sutural margin, is also a specimen of *permianum*. *P. angustum* Carp. is almost certainly a distinct species; its sutural margin is so exceedingly narrow and the elytron as a whole so long that it seems beyond the limits of variation of *permianum*.

Protelytron furcatum, new species

Figure 23A

Elytron: length 6–7 mm.; width 2 mm. Costal margin convex, apex rounded; Rs arising slightly beyond the middle of the wing; base of M either coalesced with R or independent; Cu free from M, dividing with Cu1 and Cu2 almost at the middle of the wing; 4 anals present (in types); sutural margin of moderate width.

Holotype: No. 3885ab, Museum of Comparative Zoölogy; collected by F. M. Carpenter in the upper layer of the limestone. This specimen consists of a splendidly preserved elytron.

Paratype: No. 4366ab, Museum of Comparative Zoölogy; collected by F. M. Carpenter in the lower layer of the limestone. This is a single elytron, not so well preserved as the holotype.

These two elytra undoubtedly represent a species distinct from *permianum*, characterized by the late separation of Cu1 and Cu2. None of the numerous specimens of *Protelytron* which I have seen have showed a structure of the cubitus intermediate between that in *furcatum* and *permianum*.

Family BLATTELYTRIDAE

This family is represented in the new material by twenty-three specimens, most of which are especially well preserved. A study of these elytra shows that a modification of our present conception of this family is needed. The chief and almost the only characteristic which has distinguished the family Blattelytridae from the Protelytridae is the obsolescent nature of the main veins in the distal part of the elytra. The excellently preserved new specimens of Blattelytridae now show that in some species at least the venation was better developed than has previously been supposed. In *Permelytron* and *Acosmelytron subincisum*, for example, the veins extend almost as far distad as they do in *Protelytron*. The difference between the venation of these two families lies in the fact that even in the best preserved of the Blattelytridae the veins of the *entire* elytron are very weakly developed. Since drawings of the venation cannot depict this quality of the venation, they are very deceptive, indicating a closer resemblance between the elytra of the two families than actually exists. Apart from the obsolescent nature of the blattelytrid venation, the family is also distinguished by the total absence of Rs.

The new specimens of Blattelytridae also indicate that some changes are required in our conception of the genera of the family. In 1933 I placed here four genera: *Blattelytron*, *Permelytron*, *Acosmelytron*, and *Parablattelytron*. The first of these genera was based upon so small a fragment that in all probability additional specimens of this species will not be recognizable as such. All the remaining genera are represented in the new material, and the excellent specimens included show that the elytra of all genera had a better developed venation than we have assumed was present. It also becomes apparent that *Parablattelytron* Till. can no longer be regarded as distinct from *Acosmelytron*.

Permelytron schucherti Till.

Figure 23B

Permelytron schucherti Tillyard, 1931, Amer. Journ. Sci., (5) 21: 247; fig. 6.

A very well preserved elytron (No. 4344) of this specimen was found by the writer. This is much better preserved than the type, which has thus far been the sole representative of this species, and enables us to define the species more satisfactorily. The elytron is 8 mm. long and 2.5 mm. wide, which is exactly the same size as the type. I have already pointed out (1933, p. 463) that the sutural margin of the type was formed as in other members of this family, not narrow distally as described by Tillyard. The costal expansion is well developed and the elytron is shaped as in the other Blattelytridae. Sc is long, as in *Acosmelytron*, and R is strongly formed, though there is no Rs present; M is weakly developed; the branches of Cu are coalesced almost as far as the middle of the wing; they terminate far distad of their origin; only the first anal vein is apparent and that is very poorly developed. The sutural margin is narrow.

Genus *Parablattelytron* Till.

Parablattelytron Tillyard, 1931, Amer. Journ. Sci., (5) 21: 251.

Parablattelytron Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 482.

Acosmelytron Tillyard, 1931, Amer. Journ. Sci., (5) 21: 253.

Acosmelytron Carpenter, 1933, Proc. Amer. Acad. Arts Aci., 68: 480.

The two genera, *Parablattelytron* and *Acosmelytron*, were originally separated by Tillyard into different families. In 1937 I placed them both in the single family Blattelytridae, and I now think it necessary to synonymize these two genera. The difference which Tillyard considered to be of family significance, and which I regarded as of generic rank, does not exist. This supposed distinction was that in *Acosmelytron* Cu1 was present and Cu2 was absent; whereas in *Parablattelytron* Cu1 was absent and Cu2 was present. The determination of these veins was made on the basis that Cu1 was convex and Cu2 concave. It now becomes apparent that only the *vena dividens*, or at the most Cu2, is present in either of these genera, the slightly convex ridge which we had interpreted as Cu1 being the result of the breaking of the elytron along the *vena dividens*. The species of *Acosmelytron* and *Parablattelytron* therefore differ in but minor respects that do not warrant generic rank. *Parablattelytron* is the name of this genus by page precedence.

Parablattelytron subincisum Till.

Figure 23C

Parablattelytron subincisum Tillyard, 1931, Amer. Journ. Sci., 21: 251; fig. 10.

Parablattelytron subincisum Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 482.

The unique specimen on which this specimen was based was so poorly preserved that Tillyard was unable to present a satisfactory description of the species. Since some of the new specimens are better preserved than any others that have been collected, the species is redescribed here: Length of elytron, 6.5–7.5 mm.; width, 2–2.3 mm. Costal expansion well developed; sutural margin unusually narrow; Sc well developed proximally and extending almost to the apex of the wing, the distal part being weak; R strongly formed, Rs absent; M weakly formed; Cu1 coalesced with M proximally, very weakly developed and atrophied at about the middle of the wing; *vena dividens* (and possibly Cu2) well developed proximally; portions of two anal veins are exceedingly weakly formed.

Plesiotype: No. 4364ab, Museum of Comparative Zoölogy; collected in the upper layer of limestone by F. M. Carpenter, 1935. This is a specimen of an elytron, better preserved than any other which has been found.

In addition the foregoing specimen, seven other representatives of this species were collected in 1935, all in the upper layer, except the last: 4354ab, 4358–4364.

Parablattelytron rectum Till.

Parablattelytron rectum Tillyard, 1931, Amer. Journ. Sci., 21: 252.

Ten specimens of this species were collected in 1935: Nos. 4346–4353, 4356; all were found in the upper layer except for Nos. 4349–4352. Some of these consist of very well preserved elytra (e.g. No. 4348), which prove that Sc and R were long,

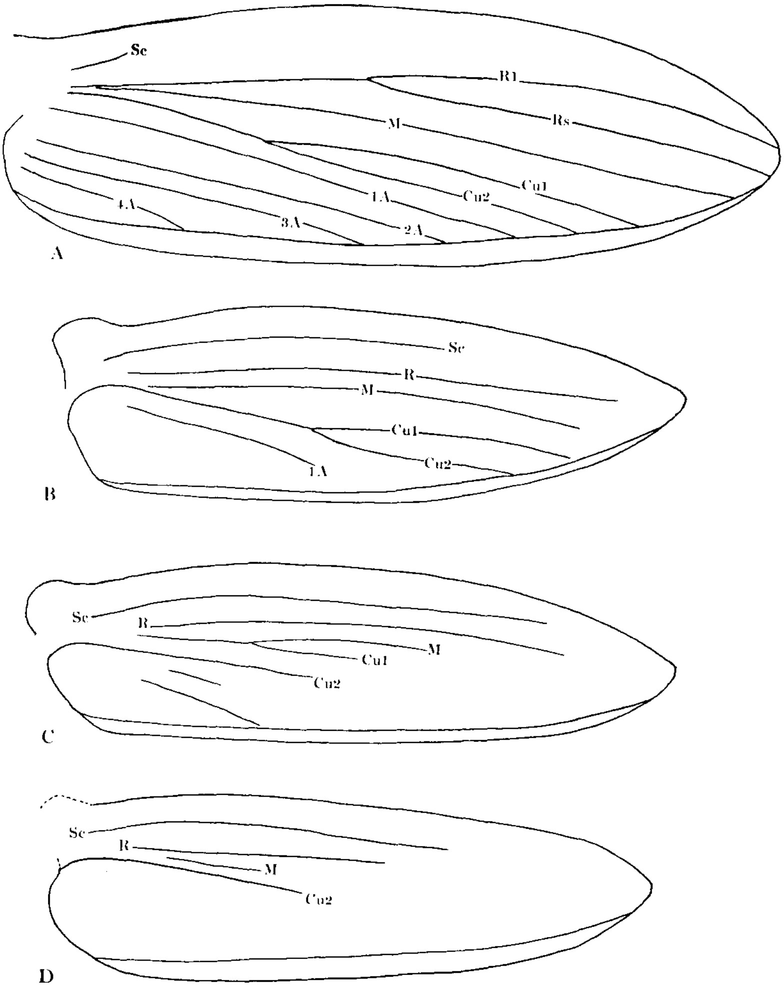
Sc
R1
M
Rs
Cu1
Cu2
1A
4A
3A
2A
A
Sc
R
M
Cu1
Cu2
1A
B
Sc
R
M
Cu1
Cu2
C
Sc
R
M
Cu2
D

FIGURE 23. A. *Protelytron furcatum*, n. sp., drawing of elytron; holotype, No. 3885ab, Museum of Comparative Zoölogy. B. *Permelytron schucherti* Till., drawing of elytron; No. 4028ab, Museum of Comparative Zoology. C. *Parablattelytron subincisum* Till., drawing of elytron; No. 1047, Museum of Comparative Zoölogy. D. *Parablattelytron elongatum* (Till.), drawing of elytron; No. 4365, Museum of Comparative Zoölogy.

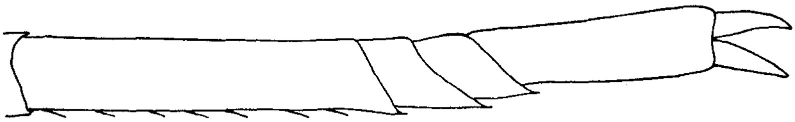

FIGURE 24. *Misthodotes obtusus* Till., drawing of tarsus; specimen No. 4388, Museum of Comparative Zoölogy.

as in *subincisum;* but no specimen shows any indication of M or Cu1.

Parablattelytron elongatum (Till.)

Figure 23D

Acosmelytron elongatum Tillyard, 1931, Amer. Journ. Sci., (5) 21: 253; fig. 12.

Acosmelytron elongatum Carpenter, 1933, Proc. Amer. Acad. Arts Sci., 68: 481.

One very finely preserved elytron of this species (No. 4365, lower layer) was found in 1935 (figure 22d). A reexamination of all known specimens of *elongatum* and *subincisum* convinces me that the elytra of these two species differ only in the width of the sutural margin (which is very broad in *elongatum*) and in the more advanced obsolescence of the veins.

Order PLECTOPTERA

In addition to numerous fragments, twenty-three fine specimens of may-flies were collected in 1935. Eleven of these are the common species, *Protereisma permianum* Sell. (Nos. 4367–4375, all upper layer except the first). Two of these add to our knowledge of the body structure of this insect. Specimen No. 4373ab, which consists of part of the wings and body, has the prothorax especially well preserved; it shows that this segment was broader and had more indications of the paranotal lobes than has previously been supposed. Specimen No. 4375ab, consisting of part of the body and wings, has one of the legs preserved in lateral view; the tarsus is seen to possess a number of prominent ventral spines, which I have not discerned in previous material.

The following species deserve further comment:

Protereisma insigne Till.

Protereisma insigne Tillyard, 1932, Amer. Journ. Sci., (5) 23: 259; fig. 18.

Since this species, the largest of the genus,[20] has previously been known only from the type and another fragment, it is noteworthy that five more specimens were found in 1935, three (Nos. 4379, 4381, 4383) in the lower layer and two (Nos. 4382, 4390) in the upper layer. Both fore and hind wings are represented in this series, and are seen to differ in the same respects as those of the other species of *Protereisma.* One proximal part of a fore wing (No. 4390), which is especially well preserved, shows Rs arising from the very basal part of M, not coalesced with it for a short distance, as is the case in the other species of the genus.

Family MISTHODOTIDAE

Genus *Misthodotes* Tillyard

Misthodotes obtusus Sell.

Figure 24

Dromeus obtusus Sellards, 1907, Amer. Journ. Sci., (4) 23: 551.

Misthodotes obtusus Tillyard, 1932, ibid., (5) 23: 261.

Six specimens of *Misthodotes* were collected in 1935, two being *ovalis* Till., and the others *obtusus* Sell. Three of the latter are especially interesting (Nos. 4387–4389, all upper layer), since they include portions of the body which have not previously been preserved. Although it has been apparent from material collected earlier that the legs were much shorter than those of the species of *Protereisma,* the details of the legs of *Misthodotes* were not known. The three specimens mentioned show these details very satisfactorily and it is interesting to note their peculiarities in this genus. In *Protereisma permianum,* the body structure of which was apparently typical of that throughout the genus, all the legs were exceedingly elongate, all pairs being from 20–23 mm. in length. In *Misthodotes obtusus,* the fore leg was only 5 mm. long (femur 1.7 mm., tibia 1.5 mm., and tarsus 1.8 mm.), the middle leg 8.5 mm. (femur, 2.5 mm., tibia and tarsus, each 3 mm.), and the hind leg, about 9.5 mm. (femur 3.5 mm., tibia 3.5 mm., tarsus about 2.5 mm.). Unlike *Protereisma,* then, *Misthodotes* had heteronomous legs, the fore pair being considerably shorter than the other two pairs. An even greater difference in the leg structure of the two genera existed in the tarsal segmentation. The tarsi of *Protereisma* were 5-segmented, the penultimate segment being the shortest. The tarsi of *Misthodotes obtusus* (figure 24) however, were but 4-segmented, the two middle segments being very short. This difference in tarsal segmentation should undoubtedly be regarded as another distinction between the two families.

The antennae, which have not previously been known in this genus, are clearly preserved in

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[20] Tillyard states (1932, p. 259) that this species is the largest known member of the Plectoptera, having a wing length of about 30 mm., but he apparently overlooked the Jurassic *Ephemeropsis trisetalis* Cock., which had a wing length of 35 mm. (Amer. Mus. Novit., 224: 1; 1924).

specimen No. 4389. They are only 1.7 mm. long, much shorter than those of *Protercisma,* but apparently consist of about 15 segments.

Order PROTOPERLARIA

Approximately two hundred specimens of Protoperlaria were collected in 1935, bringing the total number of these insects in the Museum of Comparative Zoölogy to more than eight hundred. In all collections of the Elmo fossil insects combined there are included at least a thousand belonging to this order. Before we come to an account of the new specimens, two general topics need to be clarified. One of these is the definition of the order, and the other is the nature of the characteristics on which its species may be classified.

1. Tillyard originally stated that "the sole criteria of this order are the presence of the lateral, wing-like expansions of the pronotum and the general Perlarian facies, venation and chaetotaxy of the wings." Within this order he placed the single family Lemmatophoridae. In my previous account of these insects (1935) I pointed out that inasmuch as many of the Protorthoptera had similar pronotal expansions and a wing venation very much like that of the Protoperlaria, a more precise definition of the order was needed. Since the structure of their nymphs in the Elmo limestone showed that the immature Protoperlaria were aquatic, I proposed that the order be further defined as including only those orthopteroid insects with pronotal expansions which possessed aquatic nymphs. Also, inasmuch as the adult female of Lemmatophoridae lacked a fully developed ovipositor, I suggested that the presence of such an ovipositor in the true Protorthoptera and its absence in the Protoperlaria be taken as another point of difference between the two orders. In a later paper (1937) Tillyard has added to the order the family Probnisidae Sellards (which had previously been placed in the Protorthoptera by Sellards and in the Miomoptera by Martynov), claiming that he has found aquatic nymphs of *Probnis* in the Yale collection. In this connection Tillyard again considers the definition of the order and appears to take exception to certain of my remarks. He states that the mere absence or presence of an ovipositor in an insect is no indication of the aquatic or terrestrial nature of its nymph. The truth of this assertion is so obvious that I am unable to understand why Tillyard considered it necessary to make it; there is certainly nothing in my paper which implies that I held any such notion. As a matter of fact I described in detail a very small ovipositor in one of the Lemmatophoridae (*Lecorium*) although as I pointed out this differed greatly from the long, blade-like ovipositor of the related Protorthoptera. My reference to the *reduced* or perhaps vestigial ovipositor of the Lemmatophoridae was intended only to provide a morphological character serving to distinguish the order Protoperlaria, as it was then known to us, from the related Protorthoptera, which had a fully developed ovipositor. It is obvious from my discussion of this subject, that if the Probnisidae or any related family were found to possess aquatic nymphs, and had a fully developed ovipositor in the adult, I would include the group in the Protoperlaria. Since Tillyard had no opportunity before his sudden death to explain his reasons for this association of nymphs and adults of *Probnis,* further discussion of the position of the Probnisidae will be postponed until after the remainder of the Yale collection has been returned to the Peabody Museum and I have studied the nymphs to which he referred. The account of the protoperlarian nymphs found in 1935 will likewise be given then.

2. The classification of the species belonging to the Protoperlaria (Lemmatophoridae) is not an easy matter. As Tillyard has pointed out, in order to understand the systematics of these insects, one must grasp clearly the marked tendency of the venation to vary in individuals. In his account of these insects, Tillyard indicated clearly, by illustrations and tables, the nature and extent of this variation. From his study of 210 specimens in the Yale collection, he was able to distinguish only five genera and nine species within the Lemmatophoridae. My examination of about 600 more specimens of the family substantiated Tillyard's conclusions on the variability of the venation and the number of species represented.

In a recent publication (1937), consisting mainly of a review of the literature on Palaeozoic insects between the years 1920 and 1930, Handlirsch has attempted to revise the classification of the Lemmatophoridae on the basis of the descriptions, illustrations, and tables contained in Tillyard's papers—without, of course, seeing any of the fossils themselves. In this publication Handlirsch erected two new genera and twenty-five new species of Lemmatophoridae in the Elmo limestone; and at the same time reestablished all of Sellards' genera and species, most of which had

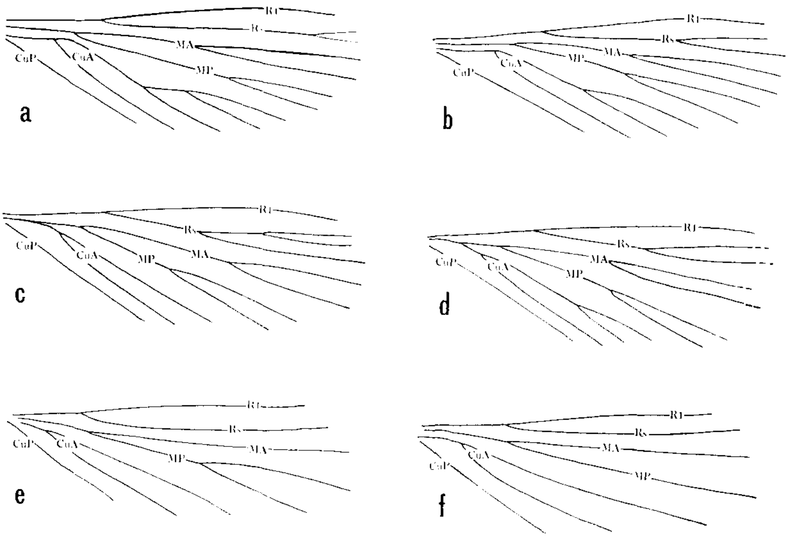

FIGURE 25. Variation of venation in Lemmatophoridae. a, b, left and right fore wings of *Artinska clara* Sell., specimen No. 4455; c, d, same of *A. clara*, No. 4442; e, f, same of *Lisca minuta* Sell., No. 3551. (See also figure 8, Carpenter, 1935).

been synonymized by Tillyard.[21] It is readily apparent that in his treatment of these fossils Handlirsch did not grasp the variability of the venation of these insects so clearly demonstrated by Tillyard. Thus, he separates the genera of the family, first, on whether or not Cu and M are joined proximally, then, on whether Rs and M are free or coalesced, and finally whether Rs is simple or forked. These, however, are precisely the venational features which are most subject to variation in these insects. Certain proof of their individual variation is provided by those specimens which possess both fore wings. Unfortunately almost no specimens of this sort were contained in the Yale collection and Tillyard was unable to demonstrate the differences in the venation between the left and right wings of individuals. A number of such specimens are in the Harvard collection, however. The fore wings of one of these (*Lecorium elongatum* Sell.) has already been figured in my previous account of the Protoperlaria (1935, fig. 8), and drawings of the venation of some of the other specimens are included here (figure 25). The specimens which have been illustrated are not unique in regard to the degree of differences in venation, but have been selected because they show the variability of the characteristics used by Handlirsch in his generic and specific classification of these insects. An attempt to determine these specimens on the characteristics used by Handlirsch shows that one wing of a specimen belongs to one of his genera or species, whereas the other wing belongs to another genus or species. Certainly, since the right and left wings of individuals exhibit such differences as these, we can only conclude that at least as great a variation takes place in the wings of different individuals, especially inasmuch as none of the hundreds of isolated wings which have been found are alike in these respects, and all show various degrees of intergradations. It is perfectly clear, therefore, that none of Handlirsch's new genera and twenty-five new species are valid. The synonymy of these is indicated in the list of species given below.

The Protoperlaria contained in the 1935 collection are as follows:

Family LEMMATOPHORIDAE

Subfamily LEMMATOPHORINAE

Lemmatophora typa Sellards

Lemmatophora typa Sell., 1909, Amer. Journ. Sci., (4) 27: 162.

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[21] To a certain extent, Tillyard may have misled Handlirsch by his use of the word "variety" for a number of individuals which showed venational peculiarities not previously mentioned by Sellards. In no case, however, did he actually name these so-called varieties, and it is at once clear that he did not use the term as indication of a trinomial nomenclature. It seems to me that the policy of naming varieties (trinominals) of fossil insects, known from wings or wing fragments, is entirely meaningless.

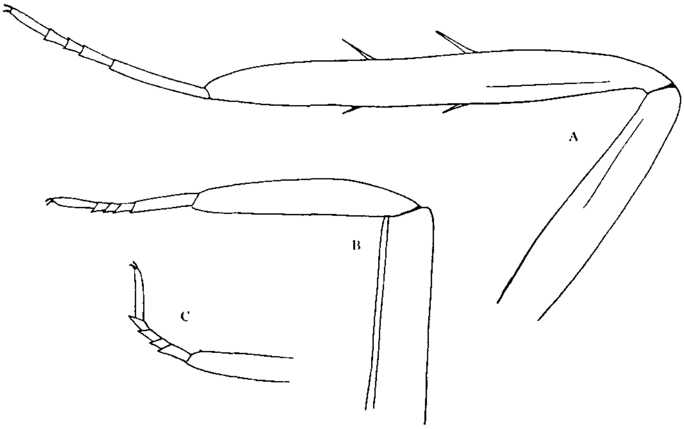

FIGURE 26. *Artinska clara* Till., drawing of legs; A, hind leg (No. 4444); B, middle leg (No. 4456); C, fore leg (No. 4456).

Eighty specimens of this species were collected in 1935, of which thirty are from the lower layer. This increases the total number of known specimens of this species to very nearly four hundred. Although some of these are fairly complete insects (e.g., no. 4426ab), none of them add to our knowledge of the structure of this common species.

Lisca minuta Sell.

Lisca minuta Sellards, 1909, Amer. Journ. Sci., (4) 26: 163.

Lemmatophora cubitalis Handlirsch, 1937, Ann. Nat. Mus. Wien, 48: 93.

Eighty-five specimens were collected in 1935, all but fourteen of which are from the upper layer. Some of these are excellently preserved, showing nearly the complete body (e.g. Nos. 4430–4433); but the structure of this insect is already well known.

Artinska clara Sell.

Artinska clara Sellards, 1909, Amer. Journ. Sci., (4) 26: 165.

Artinska inversa + *pentamera* + *tillyardi* + *nova* + *simplex* + *altera* + *maculipennis* + *reducta* + *kansasia* + *aucta* + *banneria* + *confusa* + *quadrifida* Handlirsch, 1937, Ann. Nat. Mus. Wien, 48: 95.

Fifty-four specimens of this species were collected in 1935, of which twenty came from the lower layer of the limestone. Several of these specimens are better preserved than any which have previously been found, and show body structures previously unknown, such as fore and middle legs. All of the following fossils consist of both wings and portions of the body: Nos. 4436, 4437, 4438, 4439, 4440, 4442, 4443, 4444, 4446, 4449, 4450, 4455 and 4456. The fore leg (fig. 26) which is well preserved in specimens No. 4455 and 4456 is much shorter than the other legs; the tibia is only 1.5 mm. long, and the tarsus but 1 mm. The first four tarsal segments are very short, and almost equal in length, the first being very slightly longer than the others; the fifth segment is equal in length to the previous three combined. The middle leg (fig. 26; specimens No. 4444, 4436) is at least 6 mm. long; the femur as preserved is 2.5 mm. in length, and the proximal part is not preserved; the tibia is 2 mm. and the tarsus is 1.5 mm. The first tarsal segment is greater in length than the next three combined, which are short and equal, the last segment is nearly as long as the first. The hind leg of *A. clara* (fig. 26) has already been described (Carpenter, 1935, p. 120), and it is interesting to note that the structure of the hind legs of the new specimens (No. 4456, 4444, 4455) agrees in all details with that of the earlier fossil. This leg is better preserved in the 1935 specimens however, and shows several large tibial spines not previously observed in *Artinska,* though they have been found in *Lemmatophora typa.*

Specimen No. 4456 is of special interest because it is a laterally preserved insect and shows abdominal appendages which are like those of *Lecorium* and which appear to represent a reduced or vestigial ovipositor.

Artinska ovata Sell.

Artinska ovata Sellards, 1909, Amer. Journ. Sci., (4) 26: 168.

Orta tillyardiana + *sellardsiana* + *reducta* Handlirsch, 1937, Ann. Nat. Hist. Mus. Wien, 48: 96.

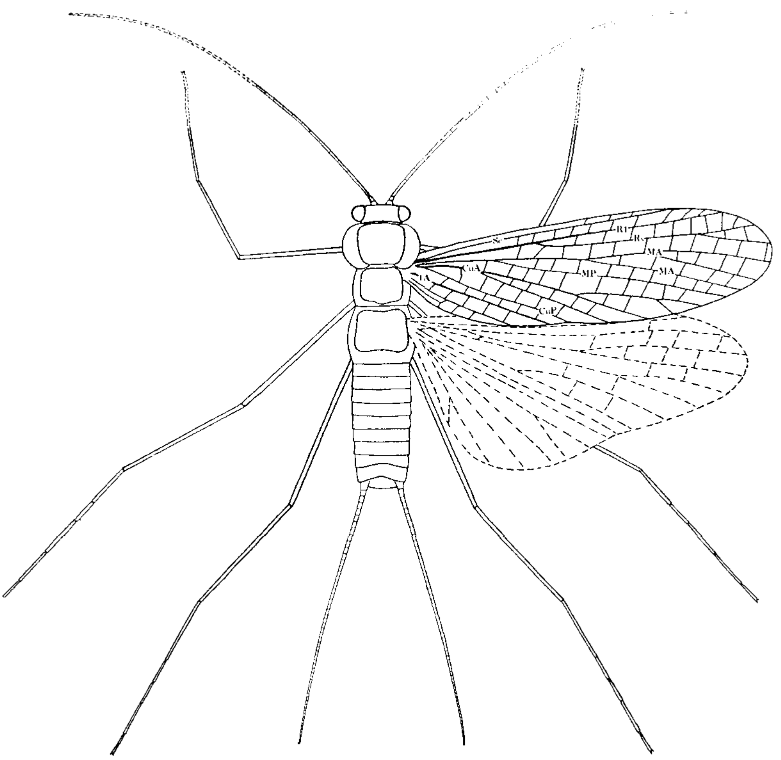

FIGURE 27. *Paraprisca grandis* Carp., reconstruction, based on specimens numbered 4457ab, 4451ab, Museum of Comparative Zoölogy.

Only twenty specimens of this species were collected in 1935, half of which came from the lower layer. This is consistent with my previous suggestion that *ovata* is much less common in the upper layer of the limestone than in the lower, for most of the collecting in 1935 was done in the upper layer. Some of these fossils show the general form of the body, and one (No. 4448) includes the cerci and a hind wing, neither of which have previously been found. The cerci are 2.5 mm. long. The venation of the hind wing is like that of *clara:* Rs is forked, MA is unbranched, MP is forked, and CuA has the fork characteristic of the family.

It should be noted in passing that the wing venation of the specimen illustrated in my previous account of the Protoperlaria (1935, fig. 4) is not entirely typical of the species in the form of the radius. There is usually not quite so much curvature at the origin and at the distal part of Rs.

Subfamily PARAPRISCINAE

Paraprisca fragilis Sell.

Paraprisca fragilis Sellards, 1909, Amer. Journ. Sci., (4) 26: 167.

Lemmatophora longipennis Handlirsch, 1937, Ann. Nat. Hist. Mus Wien, 48: 93.

Twelve specimens of this curious insect were collected in 1935; seven of these are from the upper layer and these constitute the first specimens of the species taken in that level of the limestone. None of these show any portions of the body that have not already been described; the structure of the fore and middle tarsi is still unknown.

Paraprisca grandis Carp.

Figure 27

Paraprisca grandis Carpenter, 1935, Proc. Amer. Acad. Arts Sci., 70: 128, fig. 6.

Paraprisca grandis Tillyard, 1937, Amer. Journ. Sci., 33: 97.

Paraprisca stigmatica Tillyard, 1937, ibid., p. 97, fig. 5.

Four specimens of this rare species were collected in 1935, all in the upper layer of the limestone. Two of these (Nos. 4457, 4451) are very nearly complete specimens and show much of the body structure, which has not previously been known at all.

As Tillyard pointed out, certain of the veins were incorrectly labelled in my original figure of this species, although the description of the venation was accurate. The vein marked CuP is 1A, CuA3 is CuP and CuA2 is CuA3. The correct labelling is shown in figure 27 of the present paper.

The new fossils show that some modification of our conception of this species is needed. In the type specimen, Sc was considerably shorter than it seemed to be in *fragilis* and CuA had an unusual mode of forking. The new specimens of *fragilis*, however, show a variation in the length of Sc not previously noted, and the new *grandis* also demonstrates a similar variation in the length of this vein. Similarly, the forking of CuA is not the same in any two specimens of *grandis*, so it is apparent that this species is just as variable in venation as the other members of the family Lemmatophoridae. The two species, *fragilis* and *grandis*, do not apparently have any venational differences which are constant enough to separate them. That two species are represented is, however, unquestionable, *grandis* being nearly twice the size of *fragilis*, and the body structure being decidedly different, as shown below.

Tillyard's *stigmatica* is without doubt a synonym of *grandis*, in my opinion. The size of the wing (14 mm.) falls within the range of that of *grandis* (14–18 mm.). Tillyard separated the species from *grandis* on the basis of a different form of fork on CuA, and the presence of a pterostigma. The useless nature of the forking of CuA as the source of specific characteristics has already been mentioned; there are no two specimens of *grandis* which are alike in the form of CuA and the variations range all the way from that of the type of *grandis* to that of the type of *stigmatica*. In regarding the presence of the pterostigma as specific in nature, Tillyard has overlooked the differences in the appearances of the wings when they are preserved. It should be noted that the pterostigma of this *stigmatica* is not a thickened area of the wing, but is merely indicated by the presence of a patch of brown pigment. The paratype of *grandis* consists of a wing which is slightly brownish over its entire surface but a slight darkening of the area is present in the pterostigmal area, and along the whole of R1, as described by Tillyard in *stigmatica*. The holotype of *grandis* and the other specimens of the species have colorless wings, which is in accordance with my previous remarks on the individual variation of the coloration of the Kansas fossils. I am therefore led to conclude that, inasmuch as there are no valid venational differences between *stigmatica* and *grandis*, the specimens of the former are simply those which during preservation have lost all the wing coloring except that of the pterostigmal area and the region of R1.

The body structure of *P. grandis* is so well preserved in the two specimens already mentioned that we are able to form an even better idea of the general habitus of this insect than we are of *fragilis*. As in the latter, the legs of *grandis* are long and slender, but their tenuity is carried to a remarkable extent (figure 27). Both of the specimens which show the body structure are approximately the same size, and the dimensions of the appendages are very nearly identical in both fossils. The body, including the cerci, is 25 mm. long, the cerci being 12 mm. These are much larger figures than in the case of *fragilis*, with a body 5 mm. long and cerci 1.5 mm. long. The antennae are preserved to only a length of 6 mm. in one specimen of *grandis* and 7 mm. in the other; in view of the long antennae in *fragilis*, I presume that those of *grandis* are probably at least 16 mm. in length. The preserved antennal segments of *grandis*, however, are proportionally twice as long as those of *fragilis*.

The head is well preserved in only one specimen (No. 4451). The eyes are much larger and more bulging than those of the other Protoperlaria, if our interpretation of the head structure of the other species is correct. The thoracic segments and the nota are typical of those of the Lemmatophoridae; the thorax as a whole is 6 mm. long. The paranotal lobes are very small, but are nevertheless distinct. The abdomen, which is 5 mm. long, possesses the lateral gill vestiges characteristic of the family. The cerci are extraordinarily long, very nearly equally the length of the whole body proper, and including about fifty segments. The legs of *grandis* are truly astonishing. Even the fore pair are at least 12 mm. long, and the middle and hind pairs are 21 mm. in length. Proportionally, therefore, the legs of *grandis* are even more elongate than those of *fragilis*. The dimensions of the leg segments are as follows: *fore leg*, femur, 5 mm.; tibia, 4 mm.; tarsus, at least 3 mm. (incomplete); *middle leg* and *hind leg*, femur, 7 mm.; tibia 6 mm.; tarsus 8 mm. The tarsus of the fore leg is not completely preserved and its segments are not clear. Only the first two tarsal segments of the middle leg are preserved; the first is about twice as long as the second. The first two and the last of the hind tarsal segments are clear; the first is about three times as long as the second and twice as long as the last.

In figure 27 I have presented a restoration of this insect, based on the two specimens indicated. Those parts represented by broken lines are purely hypothetical, since they are not preserved in the fossils. The hind wing is not known at all, but I have added the hind wing of *fragilis* in order to give as completely as possible the general habitus of the insect; in all probability the hind wing of *grandis* does not differ materially from that of the genotype (*fragilis*).

Genus *Lecorium* Sell.

Lecorium Sellards, 1909, Amer. Journ. Sci., (4) 26: 167.

Paralecorium Handlirsch, 1937, Ann. Nat. Musm. Wien, 48: 96.

Metalecorium Handlirsch, 1937, ibid., p. 96.

Lecorium elongatum Sell.

Lecorium elongatum Sellards, 1909, Amer. Journ. Sci., (4) 26: 167.

Paralecorium parvum + *Metalecorium confusum* + *Sellardsia separanda* + *S. abnormis* Handlirsch, 1937, Ann. Nat. Hist. Mus. Wien, 48: 97.

Twelve specimens of this insect were collected in 1935, eight from the lower layer. This small number is undoubtedly due to the scarcity of this insect in the upper layer. None of these fossils show structures not already described. Handlirsch's new genera and species were erected on the differences of the forking of the media; the facts pointing to the synonymy of these will be found in my earlier account of the venation of this genus (Carpenter, 1935, p. 133–134).

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Explanation of Plates

Plate 1

Figure 1. Photograph of part of the 1935 Harvard quarry at Elmo, Kansas, showing the thinning of the Elmo limestone at the east edge of the quarry (left of the photograph). a, upper layer of limestone; b, lower layer.

Figure 2. Photograph of the same part of the quarry, facing east.

Figure 3. *Permoscytina kansasensis* Till. Photograph of specimen No. 3811, Museum of Comparative Zoölogy; dorsal view, showing head (a), part of fore leg (b), and long abdominal process (respiratory tube). The wings of this specimen are illustrated in text figure 17. Length of fore wing, about 11 mm.

Plate 2

Figure 1. *Archescytina permiana* Till. Photograph of holotype, No. 5111b, Peabody Museum, showing absence of independent subcosta (cf. Tillyard, 1926c, fig. 4). Length of wing, 7 mm.

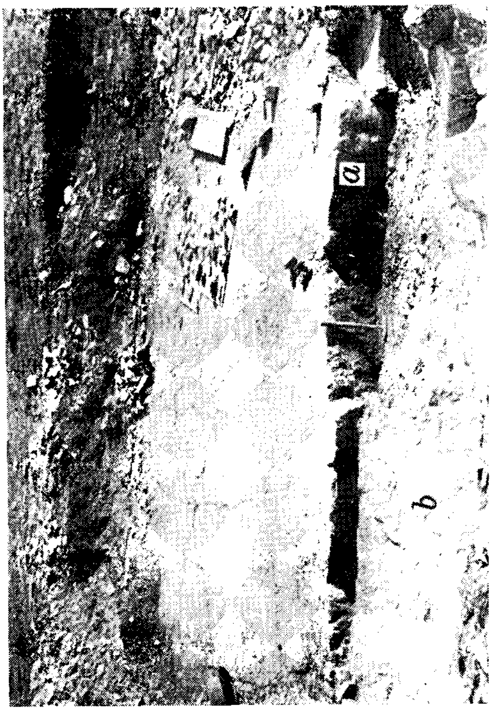
Figure 2. *Asthenohymen dunbari* Till. Photograph of specimen No. 3822, Museum of Comparative Zoölogy; lateral view, showing head and complete cerci. Length of fore wing, 6 mm.

Figure 3. *Delopterum minutum* Sell. Photograph of specimen No. 3979, Museum of Comparative Zoölogy; dorsal view, showing short cerci. Length of fore wing, 4.5 mm.

Figure 4. *Permohymen schucherti* Till. Photograph of terminal part of abdomen, specimen No. 3979, Museum of Comparative Zoölogy. Length of part shown in photograph, 2.5 mm.

Figure 5. *Permopsocus latipennis* Till. Photograph of body, specimen No. 3992, Museum of Comparative Zoölogy, showing terminal abdominal processes (corpulatory hooks?). Length of process, 1 mm.

Figure 6. *Dichentomum tinctum* Till. Photograph of end of abdomen, specimen No. 4016, Museum of Comparative Zoölogy, showing copulatory hooks. Length of hooks, .6 mm.



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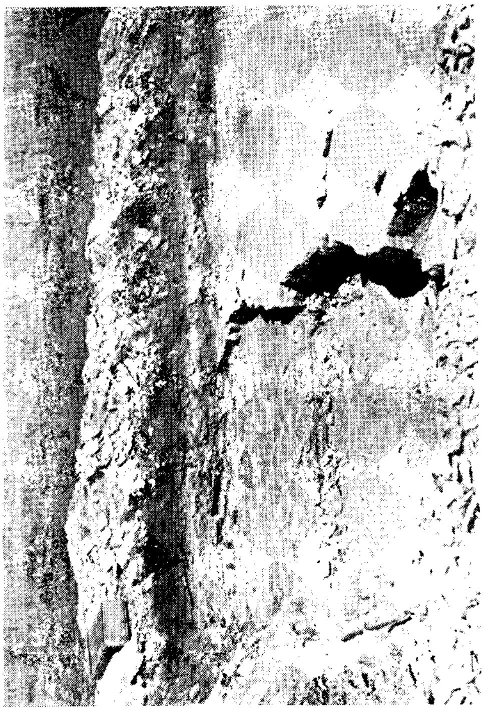

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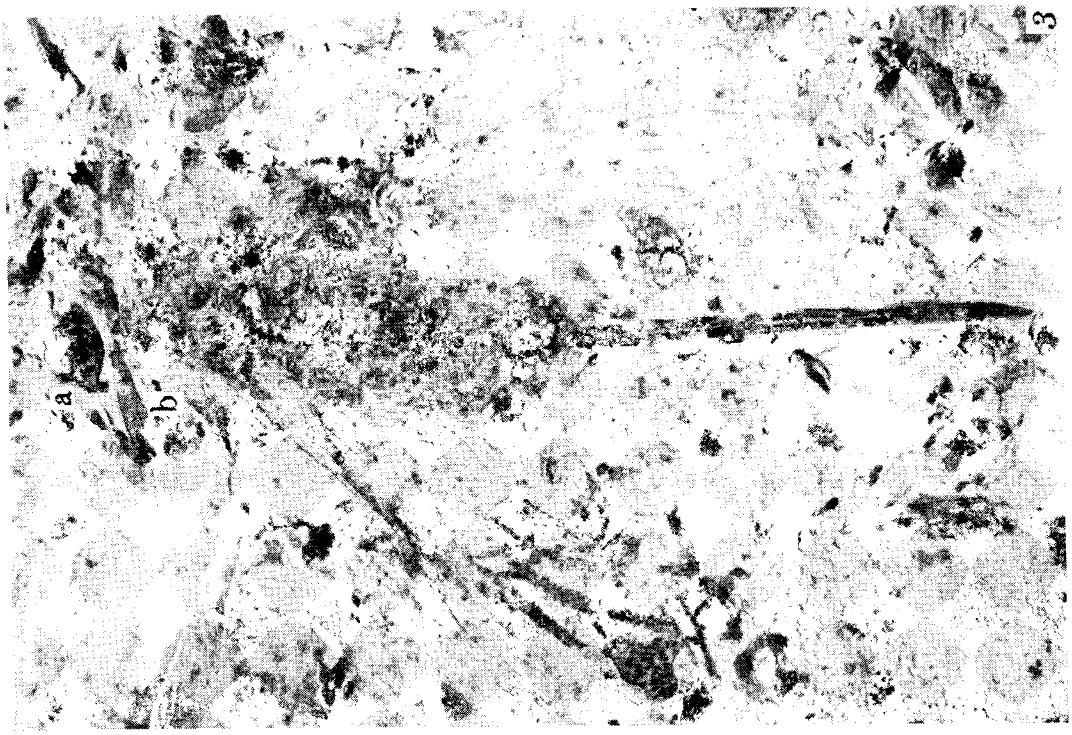

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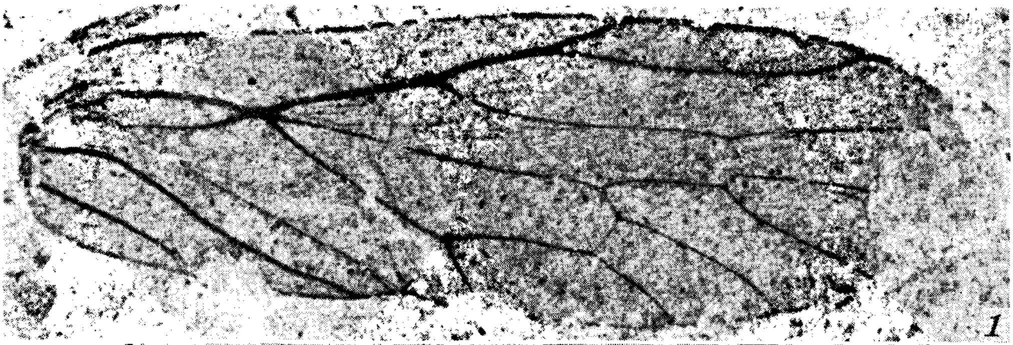
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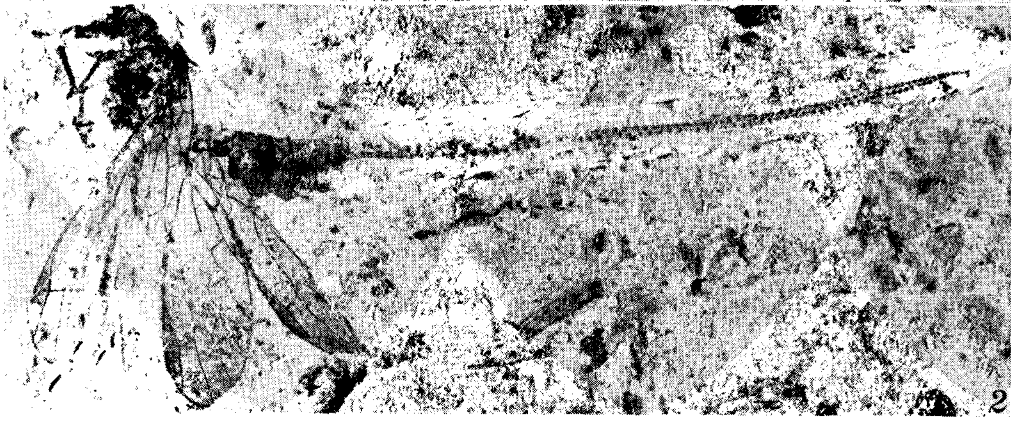
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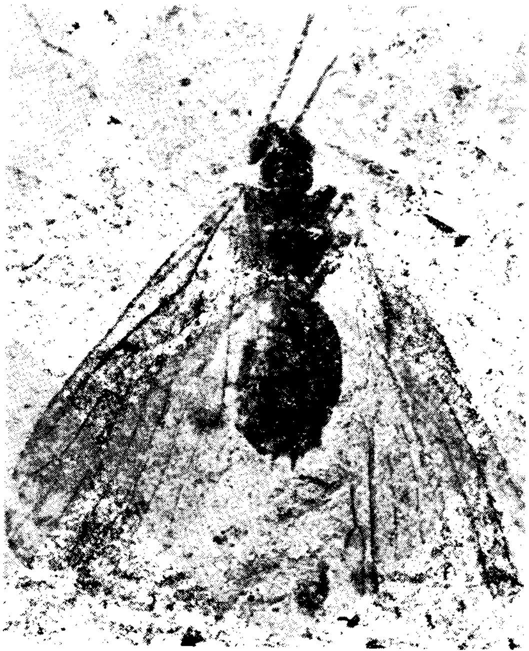
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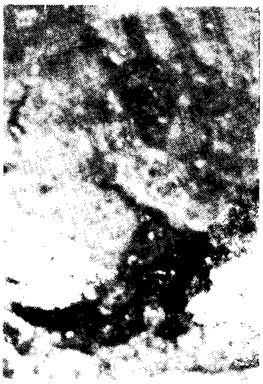
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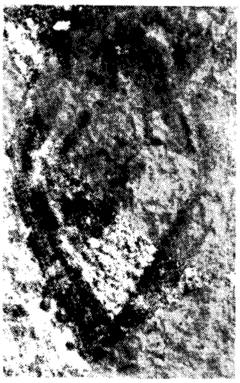
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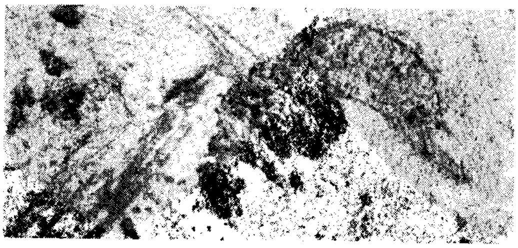
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STUDIES ON THE FAUNA OF SOME THERMAL SPRINGS IN THE DUTCH EAST INDIES

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Introduction

The writer first became interested in the insect and other animal life of hot springs on the occasion of a visit to the Yellowstone National Park in 1923. At that time he secured a small number of specimens together with data on their distribution in the thermal waters of this remarkable area, and published an account of his observations shortly afterward (Brues '24). Twice later he had the opportunity to visit a considerable number of the numerous hot springs that exist in several of our western states, notably Nevada, Utah, and California, and to make further collections in Yellowstone Park. The results of these later studies are embodied in two other publications (Brues '28 and '32) which include also a general account of the occurrence of animal life in thermal waters and the adaptations of aquatic organisms to abnormally warm environments.

Previous to this time, very few biologists had made more than incidental observations on animal life in thermal waters. Unfortunately some of these were rather carelessly made and led to highly erroneous conclusions concerning the temperature relations of a number of different forms. As I have considered these early publications previously they require no further comment at the present time. Since then several other zoologists, notably Ciofalo in Sicily and Tuxen in Iceland, have turned their attention to the fauna of hot springs while Thienemann and his associates have made numerous observations on the thermal fauna in connection with their more general limnological investigations.

Aside from material gathered by these last named workers which has been dealt with by several specialists in some recent volumes of the Archiv für Hydrobiologie under the title of "Tropische Binnengewässer" a knowledge of the fauna of thermal springs in the tropics is very scanty.

It was therefore with great satisfaction that I embraced a recent opportunity to visit, in company with my wife, several of the volcanic islands in the Dutch East Indies where we were able to collect material, and to make observations on a number of hot springs.

We proceeded first to Sumatra in May 1937, remaining until late June with the National Geographic Society-Smithsonian Institution Expedition, which was collecting living animals for the U. S. National Zoological Park under the direction of our good friend, Dr. William M. Mann. In Sumatra we visited several hot springs localities with Dr. and Mrs. Mann. On leaving Sumatra we went by the way of Bali to the northern Celebes to investigate an extensive series of hot springs in the mountains of the

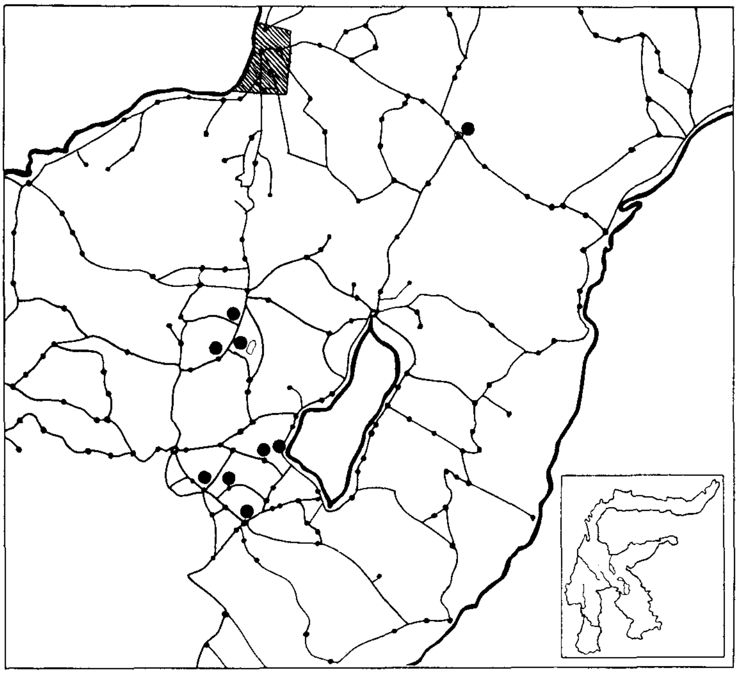

FIGURE 1. Sketch map of area surrounding Menado and Lake Tondano, showing location of hot springs. Each spring is indicated by a large black dot, the small towns by a small dot. On inset map of Celebes at the lower right, this area near the extreme northeastern end of the island.

Province of Minahasa which lies at the extreme northeast end of this island. Returning southward to eastern Java in August we visited a number of the numerous thermal springs that occur along the central mountain ridges which extend almost the whole length of the island.

Excellent roads are maintained by the Dutch Colonial government generally throughout Java, in most portions of Sumatra, in a part of Bali and in several sections of the Celebes, so that extensive travel by automobile is both convenient and expeditious. In this way we traveled some 4,000 miles during the course of our journey.

Before dealing with their fauna, it is necessary to present a brief account of the location and general characteristics of the several thermal springs or groups of springs which we were able to examine. They are in general very much like those of temperate North America both in appearance and physiographic features. A most conspicuous difference is, of course, the tropical flora that surrounds them and the fact they are in regions of heavy rainfall and luxuriant vegetation unlike most of the hot springs of the western United States which commonly arise in arid or desert portions of the country.

DESCRIPTIVE LIST OF HOT SPRINGS STUDIED

CELEBES

All of the hot springs which we visited on this island are in the extreme northeastern part, known as the Province of Minahasa. At this end the island is very narrow, the irregular north and south coasts separated by a distance of from 30 to 50 kilometers. Menado, the principal city and seaport is near the eastern end, on the north coast and the springs are grouped in the central highlands (Fig. 1) westward from Lake Tondano which is easily reached from Menado by automobile. This is an old crater lake at an elevation of about 2,300 feet and the springs are all within a few kilometers of its western shore.

Nearly a century ago Alfred Russell Wallace and Albert P. Bickmore visited this region and gave the first descriptions of several of these hot springs in the accounts of their travels in the Malay Archipelago. There were no accurate maps at that time, although Wallace gives a very good sketch map showing the springs he visited and we have been able to recognize them with certainty. It has thus been possible to make some interesting comparisons which show what changes have taken place over a long period of time.

PASO HOT SPRINGS

This group is nearest to Lake Tondano in the village of Paso which lies close to the southern third of the western shore of the lake. The springs extend for a distance of several hundred yards near the main street of the town, more or less concealed by dwellings. One spring, toward Lake Tondano from the road, includes several pools, two of them very hot and partly utilized by bath-houses built near them. Another one with a temperature of only 34° is densely covered with duckweed. Across the road is another at 47° which serves as a native place for bathing and washing clothes. This flows down the road and under it into a rice field, there it joins a warm stream that parallels the road on the east side. In this overflow the water cools to 36° and 37° in two pools where we obtained insects and snails. There is no obvious deposit about these springs which are of nearly neutral reaction (pH 7.3).

LANGOAN HOT SPRINGS

These are evidently the small remains of a once very extensive series of springs near the village of Langoan, about 11 kilometers southwest of the southern end of Lake Tondano. The only active spring is a large pool about 25 feet in diameter. It is surrounded by a natural sinter rim, but an opening in this has been plugged with concrete to increase its storage capacity and incidentally to ruin its appearance since the water-level has been raised a few inches, leaving the rim visible but covered. The flow is considerable with a temperature of 70° in the pool. This cools off where the water is led off through bamboo conduits into several pools, having cooled down to 39°, and into some bath-houses. The pools are artificially formed by the piling up of much soil, tufa, etc. The fauna includes several species of insects and abundant small frogs. Above the present spring there is a large quarry in the side of a hill where the pure white, stony sinter is mined in large quantities and chiseled into gate posts and tombstones. These may be seen in numbers scattered through the nearby towns and villages although the stone is very soft and weathers rapidly. The tufa deposits extend in the other direction toward Langoan as they are exposed for some distance along the road leading to the spring. This is evidently a permanent spring; in 1865 Bickmore visited it and found the temperature to be 78°; only eight degrees higher than at the present time. No other active springs were noted, except one well-like pit, not far away in a native's yard where it was weakly spouting black liquid mud some twenty feet below the surface of the ground. Mud on the surrounding vegetation indicated much more violent eruption during the rainy season which was past at the time of our visit in August.

AIRMADIDIH SPRING

This has been previously referred to as a boiling spring, and it apparently was extremely hot as late as 1848 according to Bickmore. When he visited it in 1865, the stream that drained it was cool. It is not far from the main road leading into the village of Airmadidih (sometimes spelled Ayer Madidi) at the base of Mount Klabat. Ascending the road from the river toward the village, it may be reached on the right hand side by a walk of about 100 yards along a bamboo-fenced lane. The spring is a large pool about 30 feet in diameter on a slight slope at the lower edge of a swampy area. It is actively flowing, but scarcely warm (about 30° C.) and is a popular place for bathing and washing clothes. The overflow runs down sharply to find its way eventually into the Tondano river nearby. This is far removed from the several other springs near Lake Tondano as it is 18 kilometers north of the town of Tondano, which lies at the northern tip of the lake.

TAKOLAN HOT SPRING

Near Tolok and just beyond the small village of Takolan is a large pool about 15 by 30 feet, with irregular outline. It is about 200 yards from the road at the edge of gently sloping ground, cultivated in maize, and is sunk in dense vegetation consisting of trees, herbs and large coarse grass. It is in ebullition at one spot near the middle, actively steaming and giving off some considerable amount of gas bubbles. At the lower end it runs off into a low flat area as a slowly flowing stream that shortly disappears into the ground at the edge of some rice fields. The water in the run-off is slightly alkaline, with a pH of 7.4 and distinctly murky from whitish clayey material in suspension. Bickmore ('69) who visited this spring in 1865 speaks of the pool as larger, 75 feet in diameter and emitting choking fumes of sulphur. It was evidently larger and more active at that time. Nearby, next to the road is a warm pool with a considerable flow serving to irrigate rice land.

In a straight line this area is only about two kilometers southwest of Paso but there is no direct road between them.

LAKE LINAU HOT SPRINGS

Lake Linau is a small body of water about one kilometer long and nearly as wide. It is west of Lake Tondano about seven kilometers in a straight line, easily reached by a very poor road leading from Lahendong to Tondangow which crosses the outlet of the lake about one and one-half kilometers out of Lahendong. In certain earlier accounts Lake Linau has been erroneously stated to be in the basin of an extinct crater on the slopes of Mount Klabat, which actually lies far to the northeast. The springs, which are near the middle of the north shore, lie to the left of the road. The water of the lake is of a greenish blue hue, but on the side next to the spring is quite turbid and milky white; between the two halves a sharp line of color demarcation is maintained.

The hot spring is at the top of a gully up a steep slope from the lake. The origin of the warm water is 40–50 feet above the surface of the lake where it arises in a swampy area. The overflow runs down with cascades here and there a foot or so in height forming a stream about twelve inches wide. The bed is lined with clayey mud mixed with small white stones and gravelly material. The water has a temperature of 38° C. and is strongly acid with a pH of less than 3.6. Hidden in the mud of the running stream are countless blood-worms that float down when the mud is disturbed. Along the gully is a gray or white deposit of clayey material that extends for some fifty feet on each side. This becomes very soft and slippery when wet.

Near the lake shore there are noticeable quantities of gas escaping, with a weak sulphurous odor. The surface for a long distance along the shore is soft, covered in places by a harder sinter which gives a hollow sound when tapped, and very close to the edge of the lake we noticed one boiling pool a few inches in diameter. Further around the lake to the north is another swampy thermal area, difficult of access.

The stream which drains Lake Linau descends through a small canyon, on the slopes of which there are outcrops of hot springs deposits indicating much more thermal activity about the lake in times past. Further down this stream are the Leilum Hot Springs next to be described.

LEILUM HOT SPRINGS

These are out of Lahendong near the road leading to the village of Leilum. Where the road crosses the stream that drains Lake Linau they are on the left hand side of the road about 100 yards up the stream. At this place there is a considerable amount of deposit on both sides of the bed of the stream where the sides of the valley rise at a moderate slope. On the north bank there is no water but well up the slope are a number of small fumaroles. Across the stream there are a few small bubbling pools, some isolated mud-pots and one large boiling pool. The latter is about fifteen feet in diameter, crater-like in form, surrounded by very dark deposit showing some yellow and contrasting with the older deposits which are almost entirely pale in color. The water in this pool was at that time (early August) five or six feet below the rim of the crater, in very violent ebullition and emitting quantities of steam. Quite probably it may erupt like a geyser during periods of extensive rain. The water in the stream is clear and cold and rushes along a bed strewn with rocks and larger boulders.

SARONGSONG HOT SPRINGS

These are west of the northern end of Lake Tondano, about 15 kilometers (*via* Tomohon) to the village of Sarongsong near which the group of springs is located. Ascending a hill beyond the village in a narrow valley to the right is a mass of hot springs deposit rising sharply above the far side of a small stream. This deposit is particolored, mainly blackish, but with some red, white, and bluish. The sides of the stream are bordered by treacherous, partly dry clay, hot and steaming in places. This extends upstream for several hundred feet, bordered by vegetation, mainly coarse grass and ferns. About a quarter of a mile further upstream the valley widens out into a broad flat area several hundred yards in width. On both sides of this the land rises rather abruptly, covered with vegetation, but with deposit underlying and outcropping here and there. There are several pools near the river and an attempt has been made to level and dike the land for rice, but the soil is clay with many twigs and decayed vegetation and the water bluish white with suspended clay. Most of the pools contain much material in suspension, either yellowish white or blackish. There is one clear and very hot pool of small size and other larger ones only moderately warm. Further out are desolate flats with patches of pale yellowish efflorescent deposit, a few steaming fumaroles, but no pools nor vegetation. On the whole this area appears to represent the vestiges of former large and active thermal basins.

TEMBER HOT SPRINGS

These springs and mud pots were described by Bickmore as lying two and one-half kilometers from Tompaso, and Wallace, giving them no name, reached them from Langoan. They lie between these two places and near the village of Tember which is about two and one-half kilometers east of Tompaso. From Tember the land spreads out in an extensive flat plain toward the south and east and the springs are scattered in this area, with numerous mud pots occupying the slope of the hill toward the north and east. On the north side of the road on this slope is an area of much crusty white deposit, very hot to the touch in places and with some treacherously soft spots. Springs are absent here, but there are several fumaroles, one forming a small steaming cone and there is much sulphur odor. Across the road back of a native kampong the slope has a number of pits and tunnels where the natives are mining the white deposit for whitewash; these openings emit considerable steam and fumes. Below the pits in a slight hollow are a number of very active mud pots with gray mud, surrounded by a crust which was colored brown, rust red, yellow, and white. These are probably much more active during the rainy season. Down a grassy slope to the south is one very hot pool with a hard sinter rim on which native women were pounding clothes that they were washing in the pool. Below this a shallow pool has been made by banking with sod and mud, used as a drinking place for water buffalo. From the vantage point of the mud pots one looks over the flat area where there are scattered groups of palms and some small woodlands but most of the area is diked for rice fields. Scattered among the trees and palms are a number of steaming pools which are diked where possible with ditches leading the water to other pools where it cools and can then be turned into the paddy fields. The hot springs are best reached by a lane which leads to the south from the road further down the hill. It is possible to reach the springs only by following the mud and sod ridges between the paddy fields and some are inaccessible because of the soft swampy surroundings. There are several steaming springs toward the mudpots on the slope but separated by palms and woodland. To the west are more paddy fields and steaming springs, scattered palms and woods and some grasses; in this area there were two or three large, almost dry, mud pots.

SUMATRA

All of the thermal springs which we visited in Sumatra are located in the northern portion of the island as shown on the accompanying outline map (Fig. 2).

SIPIROK HOT SPRINGS

These are located within two or three kilometers of the town of Sipirok which is on a new direct road recently opened between Padangsidempoean and Taroetoeng. The distance from Padangsidempoean to Sipirok is 38 kilometers.

The springs form two groups. The largest is about two kilometers from the town by road and an additional walk of about one and one-half kilometers through rice fields and a lane to a small village where the springs are located. There are two large pools, about 30 feet in diameter, one with cemented walls in use for washing clothes and the other more or less in its original condition, although banked up to a higher level. The temperature of the water in the unwalled pool is 42° C. It is alkaline with a pH of 8.6 and specific gravity of 1.0036.

The springs of the second group are three kilometers by road from Sipirok. One large pool about 20 x 30 feet is connected with a bath-house and is used for washing. A second pool of nearly the same size contains much floating vegetation. In connection with these pools there is considerable overflowing water and seepage. The highest temperature of the water is 44.5° C., pH 8.6, and specific gravity 1.0026. A number of insects were obtained in the overflow from these springs as they meander down into the adjoining rice fields.

PANGGALOAN HOT SPRING

This is on the road from Sipirok to Taroetoeng, 30 kilometers before the latter town. The water rises in a narrow pool next to the road (on the right) and flows for a distance of several hundred feet in a shallow ditch next to the road. The bottom is of blackish, soft, muddy soil and the edge soft and swampy. At the end of the ditch the water is led off under the road and finally to the river nearby. For a distance of several kilometers in the vicinity the road passes through hot springs deposits of clayey material, but no other actively flowing thermal water was observed.

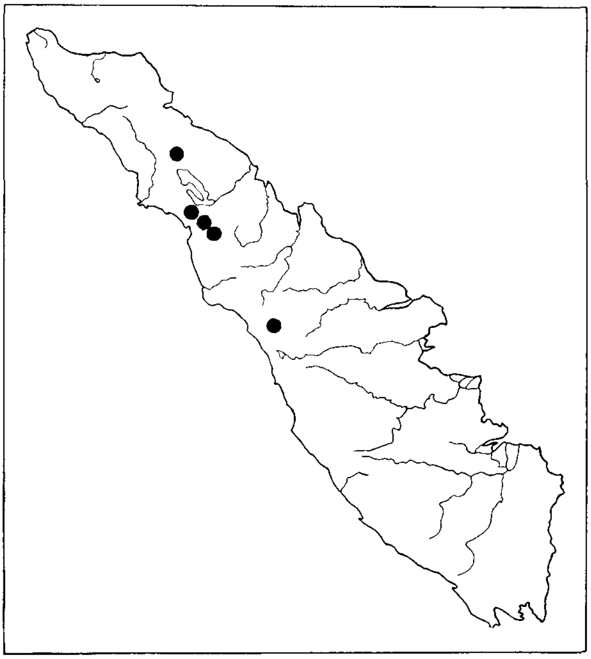

FIGURE 2. Sketch map of Sumatra, with the hot springs visited each indicated by a black dot.

TAROETOENG HOT SPRING

This is a very large spring just north of Taroetoeng near the outskirts of the town. It lies near the eastern side of the highway in an extensive area of several acres of white deposit. This deposit forms a rounded sloping mass some fifty feet in height with the surface contour broken at one place by a clear-cut group of terraces. Over these the water is flowing and the surface is stained with orange, green, and blackish due to algal growth. The crest of the deposit is steaming where the hot water emerges, and behind there rises a large wooded hillside underlain by tufa which is exposed here and there. At the foot of the slope the deposit is nearly level, including a couple of natural shallow pools, but below this the overflow has been impounded above the highway by a series of dikes which surround it and form an artificial pool several feet above the road which passes over tufa deposit at this point. This pool is nearly an acre in extent and filled with milky white warm water holding chalk in suspension, the latter probably due in great measure to the extensive use of the cooler part of the pool for bathing and swimming by the native population. At the southern end the overflow is led off at a temperature of about 40° as a good-sized stream that flows under the road to follow a course through dense vegetation to the westward into the nearby river.

The main area of deposit is bare of vegetation, but this creeps in rapidly from the sides, sometimes to become engulfed and thickly encrusted by dazzling white deposit. Most conspicuous among the encroaching vegetation are grasses, ferns, and isolated, apparently rapidly growing, naturalized agaves.

This spring is in general appearance similar to some of the sloping and terraced deposits about Yellowstone Park. The water has a pH of 8.4 which is almost exactly that of some of the water at Mammoth Hot Springs in Yellowstone Park where the same type of massive white deposit is laid down; the specific gravity of the water is 1.0074. Treatment of some of the material with hydrochloric acid dissolves it completely except for a very slight turbidity, showing it to be a practically pure calcium carbonate.

BRASTAGI SULPHUR LAKE

Eleven kilometers north of Brastagi on the road to Medan a path leads off on the right hand of the highway to the sulphur lake which may be reached by a walk of ten to fifteen minutes. The lake covers fully an acre, surrounded by jungle of a peculiar type which includes a large proportion of stunted, more or less gnarled trees. This striking modification in the vegetation also extends less noticeably along a small stream that drains the lake, and would appear to be due to peculiarities in the soil or atmosphere in proximity to the sulphur lake. The edge is swampy near the outlet with sparse vegetation and about the shore here and there are remains of dead trees and shrubs coated at the base with white deposit. At the head of the lake the water is in constant, very gentle ebullition, although only warm, where it rises next to a rough shore of large, irregular, white rocks. The water is milky white, due to clay in suspension, with a faint sulphurous odor. It is noticeably acid (pH 6.5) with a specific gravity of 1.0046 and distinctly thermal with a temperature of 32°–34° C. The insect fauna includes water beetles, Hemiptera, and chironomid midges, both in the lake and the stream which drains it.

"Poison Springs"

The fumes arising from some of the Sumatran hot springs are reputed to be highly poisonous. One of these so-called poison springs is located in a government forest reserve not far north of Loeboeksikapang or some 85 kilometers north of Fort de Kock in middle Sumatra. This is visible in the dense jungle as a cloud of steam rising among the tall trees. At the edge of the highway nearby there are a few small seeps of water at which we saw numerous butterflies attempting to drink. A few dead or moribund specimens had evidently succumbed to some poisonous substance, probably an arsenical, in the water. The Dutch government has placed conspicuous signs in both Dutch and Malay warning visitors not to approach this spring too closely.

Java

Material was collected and observations made in several Javanese hot springs areas rather widely distributed over the island. The general location of these is indicated on the accompanying map. (Fig. 3).

Hot Wells of Batoe

These are in eastern Java, almost directly south of Sourabaja at a distance of about 100 kilometers by the highway, *via* Malang, and midway between the north and south coasts. They have been generally called "Hot Wells of Batoe" although they are actually at Songgoriti, a village just north of Batoe. The springs lie slightly off the highway and may be located by a hotel that has been built next to them, equipped with the usual bath houses. The permanence of the wells is indicated by very dilapidated Buddhist ruins immediately next to them. They are on an open slope at an altitude of 3,800 feet, behind which the mountains rise sharply at least 1,000 feet above. As the flow of water is slight the several wells have been inclosed in covered cement basins, the largest one in apparent ebullition, but with a temperature of only about 53° C. In the enclosed space above this well there is an odor of sulphur dioxide but the pH of nearby seeps is rather high (7.2). In shallow seeping pools next to a second, smaller well at temperatures of 35°–37° we obtained larvae of mosquitoes and stratiomyiid flies and one species of beetle.

From the mountainside above, the springs are seen to emerge at the foot of the steep slope where the land surface assumes a gentle slope southward towards Batoe.

Hot Wells of Krakal

These are on the southern side of the mountains not far from the south coast and practically at the middle of the island. They may be approached by a winding road from Keboemen beyond which they arise in the foothills at a distance of about eleven kilometers. The water in two enclosed concrete basins is 41° and 38° respectively and apparently devoid of animal life. In the neigh-

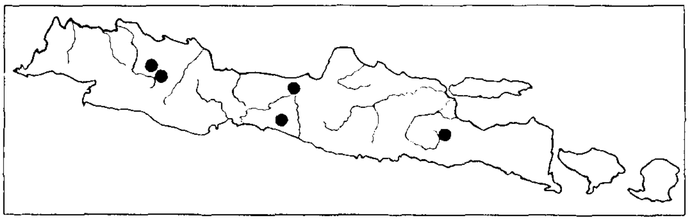

Figure 3. Sketch map of Java, with the hot springs visited each indicated by a black dot.

borhood there is practically no evidence of older hot spring deposits.

Dieng Hot Springs

These are adjacent to the Dieng Plateau at an elevation of about 7,500 feet, north of the town of Wonosobo. The region is near the middle of the island, nearer to the north than to the south coast. An automobile road, 24 kilometers in length has been recently completed which ascends the mountain from Wonosobo to the village of Dieng. The thermal waters are about two kilometers south-west of the village, south of the swampy plateau proper. One large spring is particularly interesting as it was described nearly 100 years ago and is still in practically the same condition. This is a boiling pool some twenty feet in diameter in the center of which are several irregular jets of water that spout alternately to the height of several feet (cf. Peale, '83, p. 350). The early account speaks of the water rising to a height of 3–4 feet. This is evidently an old spring, once much larger, as it lies at the foot of a sloping mass of deposit about an acre in extent. The overflow of this pool is thick with dark gray mud covered with a thin superficial layer of water, but contained some insect life. It is quite acid, with a pH of 6.3. There are also numerous fumaroles, a small stream of very hot water and several small ponds of sulphurous, but not warm water in the neighborhood.

Kamodjan Hot Springs

These are in western Java northwest of Garoet, reached by a toll road that climbs Mount Goentoer for a distance of 22 kilometers from Trogon, a village just north of Garoet. The thermal activity extends over an area of some ten acres in a shallow basin or flat valley about a quarter of a mile in diameter. Beyond, the land rises much more abruptly to the top of the mountain. There are numerous fumaroles and steaming pits, the latter of small size but emitting much steam which rises in clouds among the tree ferns and other plants of the tropical jungle. Scattered about are also a considerable number of mud-pots, many of them small, but several attaining a diameter of twelve feet or more, filled with thick grey or buff mud. The area lies within a forest reserve and is in its natural state except for one steam vent which has been closed and fitted with a large iron pipe. Here a native performs stunts for the few tourists who venture so far from the beaten path, exploding paper bags, blowing a large bamboo whistle and creating much noise to mar an otherwise most impressive and spectacular series of natural phenomena.

This is the crater of Mount Goentoer, at an elevation of 7,400 feet. Just below are several large pools filled with warm, very murky water, their marshy edges lined with greyish clayey mud. Beyond is a bank of luxuriant herbs and ferns that merge into the adjacent jungle. These pools represent the overflow from the activity on the slope above and undoubtedly receive much more water during the wetter months.

Tjipanas Hot Springs

These are not far from Kamodjan, reached by a short side-road from Trogon. They are much lower, at an altitude of about 2,500 feet near the foot of the north slope of the mountain, and the thermal activity is confined to flowing hot water. One large spring, in connection with which a hotel and bath house have been built, is confined in a large concrete tank at a temperature of about 60° C. In a flat area below this, occupied by the native village, are a number of fish-breeding ponds supplied by thermal water at a temperature of about 40° C. where it enters the ponds. Some frogs and tadpoles were obtained here, but no fish were observed in the thermal part of the ponds.

Systematic Account of the Fauna

Insects

Collembola

So far as I am aware, no spring-tails have hitherto been reported as associated with hot springs in other parts of the world, but Handschin ('32) mentions three species collected by the Thienemann expedition close to hot springs in Java, although no temperature records are given. These species are *Hypogastrura armata* Nic., *Isotoma sensibilis* Tullb. and *Trichogaster bispinosus* Handsch., all from the borders of hot springs at Kandang Badak in Western Java.

Odonata

Libellulidae

Five species of nymphs of this family are represented in the collections from Sumatra and the northern Celebes. All are members of the subfamily Libellulinae. As there are over twenty genera of this group in the region, it has been impossible to do more than designate the several forms by numbers. In each case I have included with the data a brief description and a figure of

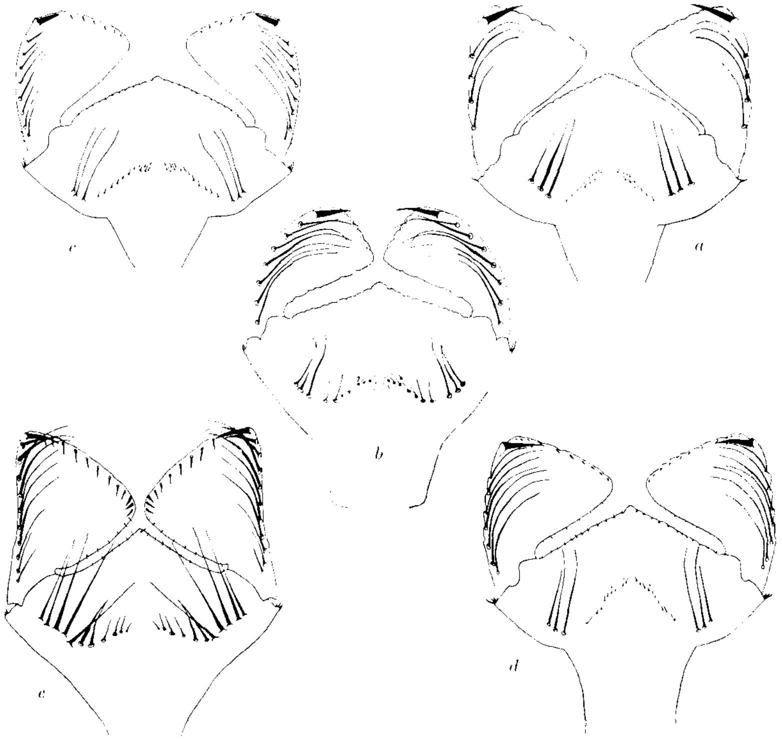

FIGURE 4. Labia of Odonata. *a*, libellulid nymph No. 1; *b*, libellulid nymph No. 2; *c*, libellulid nymph No. 3; *d*, libellulid nymph No. 4; *e*, libellulid nymph No. 5.

the labium (Fig. 4) which should make possible their recognition.

Compared with the extent of the known fauna of these islands it is evident that quite a considerable part extends into thermal water.

(**Libellulinae**) No. 1. (Fig. 4, *A*)

Very dark brown in color. Median lobe of mentum wider than long; its anterior margin weakly crenulate, not distinctly produced at the middle as a lobe. Mental setae three on each side, long, evenly spaced; between these groups with an oblique band of minute setae on each side, numbering about 12. Labial palpi with four lateral setae of nearly equal length, the margin incised at the insertion of each seta; apical margin with five or six rounded, scarcely evident teeth, indicated only by the incisions that separate them; one spine inserted at each incision. Head generally densely hairy, especially between the antennae. Legs stout; first and second joints of hind tarsi subequal, third slightly longer. Four dorsal hooks, on segments 4, 5, 6, 7, but none on the eighth. Eighth and ninth abdominal segments obsoletely toothed at the hind angle; lateral terminal appendages clearly half as long as the superior one which is very weakly concave along its lateral edges.

Three nymphs, one evidently practically full-grown, were taken in the Paso Hot Spring, North Celebes in water at 36° C.

(**Libellulinae**) No. 2. (Fig. 4, *B*)

Body stout; densely hairy, including the legs. Color pale brown, the head above much darker due to oblique dark brown stains on each side of the front. Labium with the median lobe somewhat wider than long, the margin with very fine crenulations, each notch bearing a single minute spine, the median projection quite pronounced. Labial palpi each with six or seven setae of large size, the apical margin strongly notched, each incision bearing one short and one extremely minute spine. Mental setae three on each side; medially to these with a decreasing series of eight or nine small ones and a patch of a few very minute ones at the middle. Abdomen with a median hook on segments 4, 5, 6, 7, 8, these becoming larger on the posterior segments; tergites eight and nine each bearing a short black-tipped spine at the posterior lateral angle. Lateral terminal appendage about half as long as the dorsal ones. First joint of hind tarsi two-thirds as long as the second.

One apparently full-grown nymph and numerous smaller ones; varying greatly in size, from the Sipirok Hot Springs, Sumatra, water temperature 37°. They were present in both groups of springs at this place.

(**Libellulinae**) No. 3. (Fig. 4, *C*)

Color pale brownish yellow, darker on the abdomen beyond base; body very densely hairy, especially on the thorax and legs. Labium with the median lobe slightly wider than long, with a very small, but distinct median projection in front; the anterior margin very finely crenulate, each incision bearing a very short spine; three mental setae on each side, these quite slender; between these groups is a series of setae placed in an oblique line on each side, a few of these bunched together near the median line. Labial palpi with a series of about eight setae along the outer edge, the anterior ones and the posterior one shorter than the others; apical edge not distinctly indented, but with six or seven short single spines; apical spine stout, but short. Hind legs with the first joint of tarsi much shorter than the second above, the third longest. Eighth and ninth abdominal segments each bearing a short spine at the posterior lateral angle. Lateral terminal appendage one-half as long as the superior one which is slightly concave along the sides.

Three nymphs of this form were obtained in the Lake Linau Hot Spring in water at 38°, pH 3.5. Two of these are large, one apparently practically full-grown.

(**Libellulinae**) No. 4. (Fig. 4, *D*)

Possibly the same as No. 3, but with the median lobe of the mentum much more prominent and with the anterior margin of the mentum sloping more strongly on the sides; apical edge of labial palpi deeply crenulate. Lateral terminal appendage of abdomen very short, not quite one-third as long as the dorsal one. Head with a conspicuous dark brown marking on the front between the eyes.

There are five nymphs from the Tember Hot Springs, Northern Celebes in water at 37°, pH 7.4; also one from the nearby springs at Paso, in water at 37°, pH 7.3.

(**Libellulinae**) No. 5. (Fig. 4, *E*)

Rather slender, the body almost bare except for short stout bristly hairs on the head behind the eyes and very long slender ones on the tibiae and the apex of the abdomen. Color quite pale; head finely, irregularly mottled with brown; abdomen brownish above with minute darker spots and paler markings, the latter especially toward apex. Head very short behind the eyes, the temples strongly oblique. Ninth abdominal segment with a very minute tooth at the apical angle. Mentum and labial palpi strongly bristled. Median lobe of labium angularly produced, the sides slightly concave in outline and very indistinctly toothed or crenulate. Labial palpi with ten bristles along the outer edge the apical ones long and stout, the two basal ones conspicuously shorter. Mental setae about eleven on each side, strong; the five lateral ones long, the next two shorter and the remainder decreasing in size to the median line; none, however, are really of minute size. Inner and apical margins of labial palpi very nearly smooth, the apical bristles very strong. Legs very slender; first joint of hind tarsi less than half as long as the second which is distinctly shorter than the third.

One nymph from the Langoan Hot Spring, Northern Celebes, and a second one, exactly similar, but only partly grown from the Tember Hot Springs, Northern Celebes.

COENAGRIIDAE

There is a single small nymph from the Paso Hot Springs which is perhaps a species of *Ischnura*. Zygopteran nymphs appear to be much rarer in the East Indian Hot springs than in those of America where they usually outnumber those of the Anisoptera.

HEMIPTERA

We obtained six species of the order Hemiptera in hot springs to which may be added five others previously reported from thermal waters in the same region. These belong to nine families, Nepidae, Belostomatidae, Naucoridae, Corixidae, Helotrephidae, Pleidae, Hebridae, Veliidae, and Gerridae. This series is more extensive than that recorded from North American springs, but does not include the Notonectidae which are frequent inhabitants of American hot springs. As has been found previously, none of the aquatic Hemiptera ever seem to invade water of more than very moderate temperatures, usually not extending above 36°–38° C.

I am indebted to Professor H. B. Hungerford for the identification of our material which he very kindly examined.

NEPIDAE

Laccotrephes sp. (nymphs)

There are several nymphs in different stages among the material we collected in the Sipirok Hot Springs in northern Sumatra at a temperature of 39°, pH 8.6. This seems to be the first record of a member of this family in thermal waters.

BELOSTOMATIDAE

Sphaerodema sp. (nymph)

(probably *S. rusticum* Fabr.)

The nymph which was taken in the Sulphur Lake at Brastagi, is probably this common Malayan species which has been reported from many localities in Sumatra.

NAUCORIDAE

A single naucorid nymph from Sipirok in water at 37° represents the material in this family. In America we have commonly collected species of *Ambrysus* in thermal waters.

CORIXIDAE

Micronecta sp.

Nymphs and females only of a species of *Micronecta* were taken by us in the overflow from the Panggaloan Hot Spring, northern Sumatra, in water at 37°.

Micronecta quadristrigata Breddin

Lundblad ('33) has reported the occurrence of this species in numerous places in Java and Sumatra on the basis of collections obtained by the Thienemann expedition. Among these is included the Kadjai Hot Springs in Central Sumatra near Lake Singkarak, in a swamp at 39°. A second thermal locality is the Bukit Kili Hot Springs in the same general region, in water at 38°. This is a common Indomalayan corixid.

HELOTREPHIDAE

The peculiar genus *Idiotrephes* of this small family recently described by Lundblad ('33) was collected among other localities in Sumatra in the overflow from a hot spring (Subang Ajam) near Tjurup in southern Sumatra, only in water of moderate temperature (32°–34°). Other series came from non-thermal water.

PLEIDAE

Plea liturata Fieber

Lundblad ('33) records this common Malayan species from the overflow of the Bukit Kili Hot Springs near Lake Singkarak in central Sumatra. The temperature of the water is not stated.

Anisops cleopatra Distant

This species has been reported by Lundblad ('33) from the same Bukit Kili Hot Springs in water at 38° C. Another species of the same genus, *Anisops thienemanni* Lundblad was collected by Thienemann in sulphurous water at several places on the Dieng Plateau in Central Java.

HEBRIDAE

Hebrus nipponicus Horvath

This species has been recorded by Lundblad ('33) from the hot springs at Koeripan in western Java and also from the Samosir peninsula of Lake Toba in northern Sumatra, in the latter place associated with solfataras.

VELIIDAE

Three species of this family are known to be associated with thermal springs in the Dutch East Indies.

Microvelia albolineata Torre'Bueno

This species was abundant about the borders of the Sulphur Lake at Brastagi in northern Sumatra and also in the stream that drains the Lake. It was originally described from Sumatra (Torre Bueno '27) and is known also from Bali. Another related form, *Microvelia plumbea* Lundblad was described from several localities on the Dieng Plateau in central Java all of which are associated with solfataras and sulphurous waters. The water of the Brastagi lake is acid with a pH of 6.5 and temperature of 32°–34° C.

Rhagovelia femorata Dover, var. **sumatrensis** Lundblad

This variety of an Indomalayan species was described from several localities in Sumatra by Lundblad ('33). One of these, the lime springs of Panjingahan near Lake Singkarak in central Sumatra represent thermal waters.

GERRIDAE

Limnogonus fossarum Fabr.

We collected this species in thermal water at two localities in the northern Celebes; the Langoan Hot Spring, northern Celebes and at the Paso Hot Springs. The water in these springs is 35°, pH 7.7 and 37°, pH 7.3, respectively.

The species has been previously found in thermal waters in Sumatra (Lundblad, '33), in the hot spring Subang Ajam near Tjirup, southern Sumatra and on the Samosir peninsula in Lake Toba, central Sumatra in the vicinity of solfataras. It is a widespread and abundant water-strider throughout the Indomalayan region. Another gerrid, *Ptilomera pamphagus* Breddin is recorded by Lundblad from the Subang Ajam hot spring, but without further data.

DIPTERA

As usual this order is well represented by members of several families.

CHIRONOMIDAE

Tanypus (Protenthes) punctipennis Meigen

This species, common to Europe and North America, was recorded by Johannsen ('31, p. 505) from both Java and Sumatra in the Dutch East Indies. Zavrel ('33) has studied the larvae from which some of the adults were reared and included among these is one from Kadjai, Sumatra in a warm swamp at a temperature of 39°. Our larvae are from a hot spring near Sipirok, Sumatra.

The species also develops regularly in non-thermal water, in the East Indies as well as in the other parts of its range.

The labium and glossa of a larva from Sipirok is shown in fig. 5, *g*, *h*. The median pale lobe of the mentum is narrowly incised laterally where it joins the first pigmented lateral tooth while the more lateral teeth are more deeply separated. The five teeth of the glossa are of nearly equal length, but a line joining their tips is distinctly convex. The head is barely longer than wide, about one-third longer than the antenna which bears the sense-pit just beyond the apical third of the first joint.

Metriocnemus ? sp.

A single larva from the Sipirok Hot Spring in water at 37°, pH 8.6, probably represents a

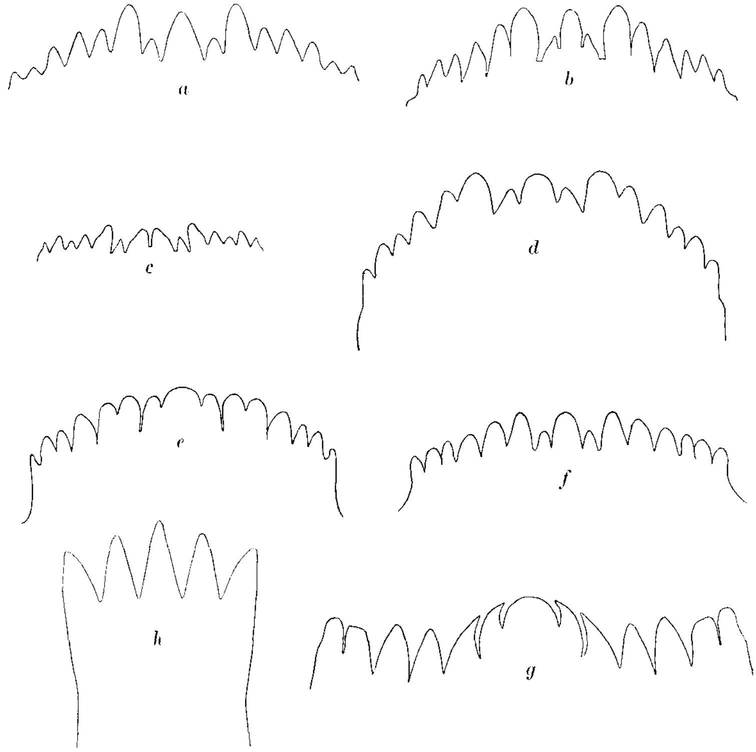

FIGURE 5. Outline of mentum of several chironomid larvae. *a*, chironomine No. 1; *b*, chironomine No. 2; *c*, chironomine No. 3; *d*, chironomine No. 4; *e*, chironomine No. 5; *f*, chironomine No. 6; *g*, *Tanypus* (*Protenthes*) *punctipennis*; *h*, glossa of same.

species of this genus. Thienemann ('32) mentions the occurrence of an unidentified orthocladiine larva which he collected in a hot spring on the Samosir peninsula in Lake Toba in Sumatra. This was living in water at 42° in the overflow of a spring in a solfatara region.

Aside from these two species there are six others from various hot springs which it has not been possible to identify with any degree of precision beyond the fact that all are referable to the Chironominae.

These are listed below, together with the localities and temperature of the water in which they were living. It is evident that members of this group commonly find a congenial environment in hot springs here as in other parts of the world, although none of our records involve water of any high temperature.

Chironominae from East Indian Hot Springs

No.	Locality	Temp. of water
1	Sipirok Hot Springs, Sumatra	37°
2	Panggaloan Hot Springs, Sumatra	
3	Panggaloan Hot Springs, Sumatra	
4	24 kilom. N. of Kotanopan, Sumatra	35°
	Brastagi Sulphur Lake, Sumatra	34°
5	Lake Linau Hot Springs, Celebes	38°
6	Kamodjan Hot Springs, Java	38°

No. 1 has three pairs of long ventral gills; the first lateral teeth of the labium deeply set off from the median one (Fig. 5, *a*) and the sensory pore of the antennae at the basal fourth of the first segment; head broad.

No. 2 has two pairs of ventral gills; the first lateral teeth of the labium scarcely set off from the median one (Fig. 5, *b*); the sensory pore of the antenna at the basal fourth of the first segment; head broad.

No. 3 lacks ventral gills; the median tooth of the labium is divided by a median notch (Fig. 5, *c*); the sensory pore of the antenna is small, placed at the apical third of the first joint.

No. 4 has the median tooth of the labium shorter than the second lateral one (Fig. 5, *d*); two pairs of ventral gills; a large sensory pore at the middle of basal third of the first antennal joint.

No. 5 is similar to the preceding, but the median tooth of the labium is broader and the first lateral one long (Fig. 5, *e*).

No. 6 has the median tooth well separated from the first lateral ones which are very short (Fig. 5, *f*); first joint of antenna with the large sensory pore just before the middle.

Chironomus (Cladotendipes) inferior Joh.

This species was reared from larvae collected at Wai Panas, Lake Ranau, southern Sumatra in water at a temperature of 40°. The larva is partially described and figured by Lenz ('37). This form is not represented in our collections.

Pentapedilum convexum Joh.

Larvae of this species were taken in a highly acid spring (pH 4-) near sulfataras at Sigaol, Samosir, Sumatra. It has been found also in a non-thermal swamp with *Sphagnum* (Lenz '37).

Some other records of Javan and Sumatran species of *Chironomus* and related genera from thermal springs are given by Lenz ('37). These include several relating to unidentified larvae from sulphurous water on the Dieng Plateau, Java and one from a highly acid spring (pH 2.7) at Sigarol, Toba Lake, Sumatra at 35.5° C., and also *Chironomus costatus*, var. *apicatus* Johannsen from highly sulphurous water on the Samosir peninsula in Lake Toba, Sumatra at 29° and pH 2.83.

CERATOPOGONIDAE

No larvae belonging to this group were obtained by us in East Indian Hot Springs. Three species have, however, been found breeding in thermal water on these islands.

Bezzia assimilis Johannsen

Arch. f. Hydrobiol., suppl. vol. 9, p. 445 (1931).
Mayer, ibid., suppl. vol. 13, p. 193 (1934) (*Probezzia*).

The type specimen was reared from a larva living in swamp water at 39° C. in the Kadjai Hot Springs near Singkarak, Sumatra. A varietal form of the species has been taken in non-thermal water at Buitenzorg, Java.

Stilobezzia notata de Meijere, var. **perspicua** Johannsen

Arch. f. Hydrobiol., suppl. vol. 9, p. 432 (1931).
Mayer, ibid., suppl. vol. 13, pp. 187, 194 (1934).

The types were reared from larvae collected at the same locality as the foregoing species, also at 39° C. Other specimens came from larvae breeding in a rice field at Lake Ranau, Sumatra.

Dasyhelea tersa Johannsen

Arch. f. Hydrobiol., suppl. vol. 9, p. 421 (1931) (*Tetraphora*).
Mayer, ibid., suppl. vol. 13, p. 180 (1934).

The larvae of this remarkable species were found living in water at 51° C. in the overflow of a hot spring near Tjibodas, Java. This is a large spring at an altitude of 2,150 meters (6,550 ft.) on Mt. Gedeh. Here the larvae were found to be living in masses in the algae that cover the rocks over which the hot water flows rapidly. This is a most remarkable record, and as might be expected the *Dasyhelea* larvae were the only animal life in the overflow.

It is well known that members of this family and the Chironomidae sometimes inhabit very hot water. The present writer once collected larvae of a species of *Chironomus* in water at 49° in a thermal pond (Brues '24) in Yellowstone Park, U. S. A., but I know of no record of so high a temperature as the 51° just cited, except one by Wood (cf. Brues, '28, p. 385) of an unidentified midge larva which he found in Owens Valley, California also at 51° C. (124° Fahr.).

CULICIDAE

The larvae of certain mosquitoes occur to some extent, although not abundantly in thermal waters. We obtained two species in the present collections. Larvae of a species of *Anopheles*, probably of *A. rossi* Giles or *A. ludlowi* Theobald were quite numerous at the Sipirok Hot Springs, Sumatra. Here they were living in alkaline water (pH 8.6) at a temperature of 38°. A second lot were in seeps about the Hot Wells of Batoe in water at a temperature of 35°–37°, pH 7.2.

Brug ('31) records *Anopheles rossi*, among other localities, from the warm surface water of Lake Lamongan, Java, which reaches a temperature of between 30° and 34° in the middle of the day. Lake Lamongan is a beautiful deep crater lake near Klakah, Java, where the daily and monthly temperature fluctuations in water temperature have been carefully studied by Ruttner ('31). The lake is some 780 feet above sea level, well supplied with floating vegetation. The surface temperature may rise to 33.8 and drop to 27.8 so that it frequently reaches 33°. At a slight depth of ten inches it is more constant, but may reach 30° or slightly higher. However in floating masses of aquatic plants the temperature may rise much higher, in growths of *Hydrilla* to 39.7°, and in another aquatic plant, *Eichhornia*, which produces also air-leaves that shade the surface the water temperature may reach 36.9°. Records of *Anopheles* from thermal springs in America show also that their larvae invade water of moderately high temperatures much more commonly than do those of other mosquitoes.

Brug also records *A. rossi* or *A. ludlowi* from a hot spring in a swamp at 39° near Lake Singkarak in central Sumatra and *A. aconitus* Dönitz from Lake Lamongan, among *Hydrilla* plants, but in the shade. In the latter case no temperature is noted, but the water was probably well above 30°.

A single mosquito larvae from Sipirok in water at 38°, pH 8.6 belongs to the genus *Culex*, but is not in sufficiently perfect condition to permit a more accurate determination. Brug ('31) records *Culex malayi* Leic. from Lake Lamongan, in *Hydrilla*, but gives no water temperature.

SIMULIIDAE

The only black-fly larvae collected were obtained in sulphur water 24 kilometers north of Kotonopan where a small warm stream passes beneath the road through a culvert.

The occurrence of members of this family in thermal waters is not general and has been recorded in only two or three instances (Brues, 1932, p. 243).

The Sumatran larvae belong to a European species, *Simulium latipes* Meigen, of which Edwards ('34) has described two East Indian varieties from Java.

STRATIOMYIIDAE

As these larvae are characteristic inhabitants of thermal waters in temperate regions it was not surprising to find them present in similar situations in the East Indies. They were found, however, only at two places, one in Sumatra and the other in Java.

A series of larvae which quite surely belong to the genus *Odontomyia* were collected in warm seeps at the Hot Wells at Batoe in Java. This water was at a temperature of 35°–37° and pH 7.2. They were extremely abundant and among them were a few that had already pupated. The body is of the usual form, with a broad dark median band containing irregular pale dots; the sides are pale, marked with black dots that form on the side of each segment two more or less clearly longitudinal series. Terminal segment in the extruded position about two and one half times as long as broad with the anal slit near the middle; apical margin seen from above, rounded and slightly sinuate between the middle and sides. Penultimate segment and the three or four segments that precede it each with a pair of hooks on the ventral margin toward the middle. Occasionally these hooks are doubled so that there are four to a segment; but this doubling seems never to appear on the penultimate or antepenultimate segment. Length from 15 to 20 mm.

It might seem that the doubling of the hooks on certain segments indicates that two species are concerned, but the larvae seem otherwise identical and the doubling is sometimes incomplete, *i. e.*, three hooks on one segment.

A single larva belonging to the family Stratiomyiidae was collected on the edge of the Sulphur Lake at Brastagi, Sumatra, in water at 34°, pH 6.5. This is elongate, of the form of *Odontomyia* or *Stratiomyia,* but evidently represents either some other genus of which the larvae are hitherto unknown, or possibly a form related to *Euparyphus*.

The antennae are inserted at the sides of the head, perhaps a little, but not much higher than in *Odontomyia*. Apical segment nearly twice as long as wide, the anal opening broad, nearly as wide as long; spiracular opening not visible from below, partly so from above as a broad transverse slit, fringed with long pectinate or plumose hairs that are slightly longer than the width of the segment. Dorsally the penultimate and four preceding segments bear a series of very small, stout, thorn-like spines near the posterior margin; these are more minute and numerous (about 12) on the anterior two of these segments. Beneath, the penultimate segment bears a pair of rather small hooks, repeated on the three preceding segments, but becoming successively smaller, the most anterior pair minute. Color dark, mottled with irregular wavy longitudinal streaks. Length 8 mm., greatest width 1.6 mm.

EPHYDRIDAE

One species has been recorded from a hot spring in central Sumatra by Cresson ('32). This is *Notiphila phaea* Hendel found by Thienemann in a hot spring swamp at 39°, adjacent to the Kadjai Springs, near Lake Singkarak. The larvae insert the posterior spiracular tube into roots of the plant, *Bacopa*. This is the third genus of the family to be found developing in thermal water. *Ephydra* is commonly found in such locations in the United States, usually, but not always, in water containing considerable amounts of sodium chloride. *Scatella* is represented by several species in hot springs. Recently Tuxen ('36a) has found a variety of the European *S. stagnalis* Fall. very commonly present in the thermal springs of Iceland. This form was originally described by Collin as a distinct species, *S. thermarum*. Also in North America, Japan, Italy, Greenland, probably in New Zealand, and finally in Kamtschatka, other species inhabit hot springs. In the latter country Malaise (*teste* Tuxen '36a) collected the larvae of *S. costalis* Hendel in water said to be at 55° C. As this temperature is decidedly higher than previous authentic records for other animal life, I believe that it should be accepted with great caution until further corroborative observations are made on the Kamtschatkan form. However, according to Tuxen ('36b) not only does *Scatella* extend into water of 55° in Iceland, but he reports finding larvae and pupae in water at 65° C.! These were presumably alive although this is not directly stated in the text of his paper. On this basis, Tuxen has been led to believe that the physiological requirements of animal life in Iceland are radically different from those in other parts of the world. This is, of course, a conclusion that will not be accepted by biologists at large without abundant proof.

OTHER INVERTEBRATA

There are contained in the reports of Thienemann's expedition to the Dutch East Indies a number of records by various workers relating to several groups of invertebrates that have not been mentioned in the previous pages of the present paper. As these are scattered through various papers in the Archiv für Hydrobiologie over a number of years, I have excerpted these and included them here for the sake of completeness. Specific citations to these papers are given in each case.

PROTOZOA

In his account of the shell-bearing Rhizopoda Harnisch ('32) lists twelve species from thermal waters in Java and Sumatra as follows:

Nebela tubulosa
Kali Tjibodas, Java, 45° C.
Nebela lageniformis
Tjibodas, Java, 45° C.
Nebela tenella (?)
Tjibodas, Java.
Quadrula discoides
Tjibodas, Java, 45° C.; overflow from hot springs at Lake Ranau, Sumatra, 58° C.[1]

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[1] It must be noted that it is not possible to determine whether minute organisms are alive in mass collections without an immediate resort to microscopical examination in the field. This is particularly true of the present

Heleopera picta
Warm Spring, Musi River, Sumatra, 32°–34° C.
Arcella vulgaris
"Hot Spring."
Arcella artocera (?)
Tjibodas, Java.
Phryganella hemisphaerica
42.7° C., no definite locality.
Cyphoderia margaritacea
Thermal water overflow, no locality.
Euglypha strigosa
Condensation zone, Tjibodas Hot Springs, Java.
Corythion pulchellum
Same locality.

Nematoda

Since the publication of the summary in my previous account (Brues '32) several helminthologists have contributed extensively to the knowledge of the nematodes that inhabit thermal waters.

Hoeppli and Chu ('32) have investigated the free-living nematode fauna of several hot springs in China and Formosa. Their collections contained material of nine species, five of which are described as new. As may be seen from the following list all were obtained in water considerably above 30°, and in several instances in a spring where the temperature reached 48.5°.

Greenia orientalis Hoeppli & Chu
Tangshan, near Nanking, China, 35°.
Wen Chu'an, near Peiping, China, 34°.
Foochow, China, 35°.
Changchow, China, 39°; 48.5°.
Plectus chengmohliangi Hoeppli & Chu
Foochow, China, 34.5°.
Microlaimoides lingi Hoeppli & Chu
Foochow, China, 34.5°.
Cyatholaimus chungsani Hoeppli & Chu
Changchow, China, 39°; 48.5°.
Monhystrella ginlingensis Hoeppli & Chu
Tangshan, near Nanking, China, 35°.
Monhystera filiformis, var. *fukienensis* Hoeppli & Chu
Changchow, China, 48.5°.
Diploscapter coronata (Cobb)
Changchow, China, 39°.
Aphelenchus parientinus Bastian
Changchow, China, 39°.
Foochow, China.
Trilobus allophysis (Steiner)
Wen Chu'an, near Peiping, China, 34°.

Two of these were later found by Schneider in East Indian thermal waters and one is common also to hot springs in Africa. While they found a number of instances where types characteristic of brackish water occurred in their collections, these were mainly ones of quite ubiquitous occurrence in varied kinds of environments. They noted also a very wide distribution in the case of thermal species, although this is of course a common occurrence among a great many of the free-living nematodes.

Recently a few nematodes from hot springs in equatorial Africa have been dealt with by De Conninck ('37). These were from Mount Banze (Lake Kivu) and include eight species, as follows: *Dorylaimus filiformis, D. juvenilis, D. paraobtusicaudatus, Plectus sambesii, Rhabdolaimus terrestris, Achromodora ruricola* and *Cephalobus persegnis*. The *Plectus* is known also (as *P. paracommunis*) from Yellowstone Park. Unfortunately no accurate temperature determinations are available as the water in which the collections were made varies between 30° and 50°.

Finally, Schneider ('37) has just published the results of his study of the East Indian free-living nematodes collected by the Thienemann expedition to Java and Sumatra. This series includes eighteen species found in the water of truly thermal springs. In the following list only actual thermal records are included although practically all of the species are recorded from non-thermal stations.

Trilobus malayanus Schneider
Wai Panas, Lake Ranau, Sumatra, 40°.
Bukit Kili Hot Springs, Sumatra, 38°.
Kadjai Hot Springs, Sumatra, 37°.
Lake Toba, Sumatra, 32°.
Prismatolaimus intermedius (Bütschli)
Tjiliwong, Tjibodas, Java, 33°.
Mononchus macrostoma Bastian
Lake Ranau (Lyngbya zone), Sumatra, 40°.
Dorylaimus flavomaculatus Linst.
Wai Panas Hot Springs, Sumatra, 41°.
Also several localities in warm surface water, 29°–33°.
Dorylaimus filiformis Bastian
Lake Ranau (Lyngbya zone), Sumatra, 40°.
Hot Spring, Musi River, Sumatra, 42.7°.
Hot Spring, Musi River, Sumatra, 46°.
Kadjai Hot Spring, Sumatra, 39°.
Dorylaimus granuliferus Cobb
Bukit Kili Ketjil Hot Spring, Sumatra, 51°.

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group as identifications are based in great part on the structure of the shell.

Plectus sambesii Micol.
  Bukit Kili Hot Spring, Sumatra, 38°.
Rhabdolaimus terrestris De Man
  Bukit Kili Hot Spring, Sumatra, 38°.
  Hot Springs, Kandang Badak, Java, 45°.
Monochromadora monhysteroides Schneider
  Wai Panas, Lake Ranau, Sumatra, 40°.
Monochromadora monhysteroides var. *longicaudata* Schneider
  Bukit Kili Hot Springs, Sumatra, 38°–41°.
  Kadjai Hot Springs, Sumatra, 37°.
Monochromadora crassicauda Schneider
  Hot Spring, Musi River, Sumatra, 42.7°.
Achromadora ruricola De Man
  Bukit Kili Hot Spring, Lake Singkarak, Sumatra, 38°.
Ethmolaimus pratensis De Man
  Lime Hot Springs, Kuripan, Java, 34.3°.
Monhystera filiformis Bastian
  Bukit Kili Ketjil, Lake Singkarak, Sumatra, 51°.
  Hot Spring, Mt. Kapuran, Laki, Java, 37.4°.
Monhystera vulgaris De Man
  Bukit Kili Ketjil, Lake Singkarak, Sumatra, 51°.
  Hot Spring, Mt. Kapuran, Laki, Java, 37.4°.
Diplolaimella allgeni Schneider
  Hot Spring, Mt. Kapuran, Java, 37.4°.
Cephalobus tenuis Schneider
  Kadjai Hot Spring, Sumatra, 37°.
  Hot Spring, Mt. Kapuran, Java, 37.4°.
Aphelenchus parietinus Bastian
  Solfatara, Samosir Peninsula, Lake Toba, Sumatra, 36.5°.

As only 79 forms were obtained by the expedition it is surprising to find that 18, or nearly 25% of the whole series occur in hot springs. If those found in the warm surface water of lakes or at temperatures above 30° along their shores had been included, the list would have been appreciably augmented.

A number of the species are widespread forms and five are common to the African springs mentioned above. None are definitely restricted to hot springs, although several appear to be most commonly represented in this environment, e. g., *Plectus sambesii, Dorylaimus filiformis;* and both are known from hot springs in other parts of the world. Species of two typically marine genera were found in thermal waters of high chloride concentration. It is noticeable, of course, that the waters of the East Indian springs generally contain only relatively small quantities of salts in solution.

ANNELIDA

One species of leech, *Limnatis* (*Hirudinaria*) *manillensis* Less. a widely distributed Indomalayan form has been taken once in thermal water (Augener '31). The record is from the Bukit Kili Hot Springs, Singkarak, Sumatra, in water at 38°.

A small oligochaete of the family Enchytraeidae, probably a species of *Enchytraeus*, is reported by Michaelsen and Boldt ('32) from a hot spring at Tjibodas, Java taken in water at 41° C. This is an interesting record, apparently the first for this group in thermal waters.

ARACHNIDA (ACARINA)

Two species of mites have recently been recorded from thermal springs in the Dutch East Indies by Vitzthum ('31) and Willmann ('31), based upon collections made by the Thienemann limnological expedition.

The most interesting one is a gamasoid mite, *Platyseius mollicomus* Berlese, belonging to the family Laelaptidae. This represents, according to Vitzthum the first instance among the terrestrial Acarina. The species is at least semiaquatic, having been found in masses of algae at a temperature of 41° in a hot spring at Tjibodas, Java.

However, among the oribatoid mites that were contained in the same collections from hot springs which has been discussed by Willmann, *Malaconothrus pseudolamellatus* Willmann was found in moss near a hot spring at Tjibodas, Java, at 35°. Individuals in various stages of development were present, showing that this is a normal habitat.

CRUSTACEA

Among the Crustacea, a number of amphipods, ostracods, and isopods are known to form a component of the hot springs fauna. Certain amphipods are often abundant, but so far none have been reported from any East Indian springs.

Copepod crustaceans do not commonly occur in thermal waters, but there have accumulated during recent years a few records. Carter and Beadle ('30) found in the swamps of the Paraguayan Chaco certain copepods, not identified, living in water that is periodically subject to rises in temperature to between 40° and 42° C. In hot springs in the Dutch East Indies, Kiefer

('33) and Heberer and Keifer ('32) have recorded five species at maximum temperatures ranging from 35° C. to 39° C. These are *Halicyclops thermophilus,* from the salt springs at Koeripan, Java at 35° (not 45° as previously stated by Menzel); *Paracyclops fimbriatus; Paracyclops eucyclopoides, Microcyclops varicans,* 39°; *Mesocyclops leuckarti,* 39°. Of these, *Halicyclops* has been found so far only at the place mentioned, at temperatures not below 37° and *Paracyclops eucyclopoides* although not an obligatory thermophile thrives better at the higher temperatures.

In his account of the Copepoda Harpacticoida obtained by the Thienemann expedition, Chappuis ('31) mentions three species from a warm spring in northern Sumatra, at Ayer Panas near Tjurup. These are *Elaphoidella bidens coronata, Schizopera tobae* and *Parastenocaris longicaudis,* from water at 29.5° which is really hardly to be considered as thermal, except for its origin.

Apparently only a single species of Ostracoda has been found in hot springs in the Dutch East Indies, although members of this order are quite well represented in North American thermal waters. This is *Stenocypris humilis* described by Klie ('32) from Sumatra. Specimens were taken in water at 39° in a hot spring marsh at Kadjai, near Lake Singkarak in central Sumatra.

Among the Cladocera two East Indian species are known from thermal springs (Brehm '33). These are *Bosmina longirostris* from Kali Djermih at Tjurup, Sumatra in water at 34°, and *Scapholeberis kingi* in a solfatara spring at Sigaol on the Samosir Peninsula, Lake Toba, Sumatra in water at 35.5° having the extremely acid reaction of pH 2.68.

MOLLUSCA

Members of three families of gastropods are included in the material that we collected in East Indian hot springs. They represent apparently the first records from this region.

LYMNAEIDAE

Lymnaea rubiginosa Michelin was taken by us in hot springs both in Sumatra and Celebes. In the Paso Hot Springs in the northern Celebes this species was common, at the moderate temperature of 36° in water of pH 7.3 and also in the Sipirok Hot Springs in Northern Sumatra in water at 37°, pH 8.6. Other species of *Lymnaea* are known to inhabit thermal waters in both Europe and North America, usually only at very moderate temperatures.

MELANIIDAE

One species of this family, *Melanoides truncatula* Lamarck was taken by us on several occasions in thermal water in the Dutch East Indies. It was present in the overflowing water at Panggaloan Hot Springs and 24 kilometers north of Kotanopan, both in Sumatra, and the Paso Hot Springs of the Northern Celebes. In all cases the temperature of the water was 36° or below.

VIVIPARIDAE

A large species of this family, *Viviparus costatus* Quoy and Gaimard, was collected by us in three thermal springs in the Northern Celebes, at temperatures of 37° or less. Following are the localities: Tember Hot Springs, 37°, pH 7.4; Paso Hot Springs, 37°, pH 7.3; spring at Airmadidih, 30°, pH 7.1.

AMPHIBIA

Frogs were obtained in two localities, one in Java and the other in the Celebes, the latter series including tadpoles also. The identifications were made by Mr. Arthur Loveridge of the Museum of Comparative Zoology, who very kindly examined the material.

Rana cancrivora cancrivora Gravenhorst

This species was taken at Tjipanas, Java in water at 40° which is an unusually high temperature for frogs. There were numerous tadpoles in the shallow water of the pool and adults about its edges which immediately dived into the water when disturbed. This temperature is approximately the same as records of 39.2°–41.6° which I have noted for the American *Rana pretiosa* Baird & Girard in Yellowstone Park.

Rana cancrivora verruculosa Roux

This form was very abundant as young and semi-adults in the Langoan hot spring in the Northern Celebes in water of considerably lower temperature (35°, pH 7.7).

COMPARISON OF THE FAUNA WITH THAT OF NORTH AMERICA

The fauna of North American hot springs is more completely known than that of any other part of the world, sufficiently so to indicate at least in a general way, what types of animal life are represented in the Nearctic thermal fauna. Some groups have unfortunately received little or no attention but among the insects particularly, and to a less extent among the Crustacea, Acarina, and Mollusca certain families and genera are known to have invaded thermal waters quite generally while others are consistently absent or very poorly represented. Also, as I have previously pointed out, there is a very noticeable similarity between the thermal fauna and that of estuaries, brackish water, and the sea. This is undoubtedly due to some extent to the common presence of dissolved salts in thermal waters and in the sea; however, there are wide differences in the saline components of thermal waters compared to the nearly uniform proportions of specific salts present in oceanic and brackish water. Although sodium chloride exceeds the other salts in some hot springs, the saline constituents of such waters are so varied both in quality and quantity that the only constant similarity is the increase in osmotic pressure resulting from their presence, and the similarity of the several faunas is undoubtedly due directly to this physical factor.

On the basis of the material secured by us in the Dutch East Indies together with the numerous previously published records which are cited earlier in the present account it is possible to compare this fauna with that of the North American continent. Such a comparison is particularly instructive as the two regions are not only widely separated, but one enjoys a temperate climate while the other lies directly in the equatorial belt.

Among insects the order Diptera is represented in North America by seven families: Chironomidae (including Ceratopogonidae), Stratiomyiidae, Culicidae, Tabanidae, Ephydridae, Simuliidae, and Syrphidae, roughly in the order listed both as to number of species, frequency of occurrence, and abundance of individuals. Of these only the first two families listed may be regarded as of very general occurrence in thermal waters. All but the last are known to be represented in East Indian springs, the others in approximately the same order of abundance, except that the first (Chironomidae) are far more abundant than the Stratiomyiidae which are relatively common in North American springs. This great difference may be readily ascribed to the fact that the family as a whole is similarly far more abundant in the Nearctic region than in Malaya. As in North America, Chironomidae have been found to invade water at unusually high temperatures, showing this family to be particularly resistant to excessive heat here also. Thus larvae of a species of *Chironomus*, *C. tentans* in North America has been taken in water at 49° and an unidentified member of the same family was reported at 51°. In Java (*vide antea*) *Dasyhelea tersa* has been found in water at 51°. Various members of this family are frequently found at temperatures of 39° or higher. Other dipterous larvae rarely inhabit water above 35°, with the exception of certain Stratiomyidae which are not infrequently found above 40°, in a couple of instances at 47°. Mosquito larvae seem to be restricted to water below 40°, but it is interesting to note that one American species of *Anopheles*, *A. pseudopunctipennis*, common to both North and South America is frequently found in slightly thermal water. This is true also of at least two Malayan species of *Anopheles*, but no larvae of malarial mosquitoes have been found living in water above 38°.

The coleopterous fauna of East Indian thermal springs appear to be more meagre than that of North America. From the latter region six families, Hydrophilidae, Dytiscidae, Helmidae, Heteroceridae, Gyrinidae, and Haliplidae have been reported, in the order listed with the first two families about equally represented and far outnumbering the others. In the Dutch East Indies only the Hydrophilidae and Dytiscidae are included in the thermal fauna. Nearly all are Hydrophilidae and two genera *Enochrus* and *Berosus* are common to the two regions. This great dissimilarity in the two faunas of thermal water beetles is in keeping with the far greater abundance of aquatic Coleoptera in temperate regions.

Among aquatic Hemiptera, in spite of more fragmentary knowledge more families are known to be represented in East Indian thermal waters than in those of North America. From the latter region six families are known, Corixidae, Notonectidae, Gerridae, Naucoridae, Nepidae, and Belostomatidae. To these must be added from the East Indies four other families, Hebridae, Velliidae, Helotrephidae, and Pleidae, but of these the Helotrephidae do not occur in the New World. The Hemiptera are, however, not highly adapted to high temperatures as none have been reported from water exceeding 39°–40°.

Odonata are known from thermal waters in both regions, both of the suborders, Zygoptera and Anisoptera represented by a few species, usually from water of moderate temperature, only rarely slightly exceeding 40°.

Among other Arthropoda a number of Acarina of several families are included in the thermal fauna. On the basis of very fragmentary knowledge it appears that mites are more abundantly represented in North America. Several species are known to extend into water above 40° and one North American species, *Thermacarus nevadensis* is restricted to hot springs where we have found it very abundantly in water as high as 50.8°. As indicated on a previous page, one aquatic East Indian species has been reported in water at 41°.

Crustaceans of several orders, Amphipoda, Ostracoda, and Isopoda are known from North American hot springs. Certain amphipods are frequently abundant in North American thermal waters although restricted to moderately warm water. None are known so far from East Indian hot springs. In North America we have collected some nine species of Ostracoda in hot springs, several in water at more than 40° and one, *Potamocypris perbrunnea*, at 50°. The latter record indicates that certain ostracods are remarkably well adapted to high temperatures. In the Dutch East Indies we secured no ostracods and only a single species has been taken there in thermal water at 39° as is noted on a previous page (p. 88). It appears therefore that the group is much more poorly represented in the Malayan thermal fauna. On the other hand, several Copepoda are known from hot springs in the East Indies, although none have so far been recorded from such waters in North America.

As indicated earlier in this paper many free-living nematode worms have recently been found in East Indian hot springs, some of them identical or closely related to species from North America whence a series of forms has been reported. Undoubtedly the thermal nematode fauna is abundant and similar the world over, and the same is undoubtedly true among the Protozoa which have been collected extensively in European and East Indian hot springs, but unfortunately not yet investigated in North America.

In spite of the differences just noted, there is a very great similarity in the thermal faunas so far studied in various parts of the world, indicating a homogeneity of composition that shows specific tendencies for certain groups of animals to invade waters of high temperature much more frequently than those of other groups that are obviously unable to do so.

THE STRUCTURAL OR PHYSIOLOGICAL BASIS OF HEAT SUSCEPTIBILITY

Although this matter still rests on a conjectural basis there is available some additional information which supplements the material included in the earlier discussion on the nature of heat susceptibility that forms a part of one of my previous papers (Brues '32).

In my earlier accounts I unfortunately overlooked a paper by Bodine ('23) dealing with the thermal death-point of protozoan cysts. Experimenting with a common ciliate, *Colpoda cucullus*, Bodine found that dried cysts of this animal could resist dry heat as high as 100° C. for periods as long as three days and still remain alive. As he describes the experiments, following exposure to heat, the cysts disclosed living organisms when placed in a proper medium at ordinary temperature. A number of earlier workers had experimented with this and various other soil-inhabiting organisms in connection with the sterilization of soil (cf. Kopeloff and Coleman '17), but only in a very general way.

Bodine's results are certainly surprising and would seem to indicate that encysted Protozoa when highly dessicated are able to withstand heating to points far beyond those that prove immediately lethal to both active and moist encysted individuals. Undoubtedly such behavior is not dependent upon the same factors that determine the heat resistance of non-encysting animals and is analogous at least to the resistance shown by the seeds of some plants.[1] This matter relating to the resistance of animal cysts and the seeds of flowering plants certainly demands further careful investigation before any dogmatic statements can be made. In spite of numerous experiments relating to the sterilization of soil, the destruction of seed-infesting insects, the resistance of spores and encysted organisms, etc., there is still lacking any series of coördinated experiments designed to demonstrate any exact relation of heat susceptibility to desiccation. It may quite likely be found that such conditions of suspended animation where metabolic processes are practically nil are not directly comparable with those of normal metabolic activity.

In a very complete and careful study of the thermal blue-green algae or Myxophyceae of the

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[1] A somewhat similar condition has been reported by Mathias ('29) for the eggs of certain phyllopod crustaceans (*Triops cancriformis* and *Branchipus stagnalis*). Heating soil containing the eggs of these animals to temperatures as high as 80° C. failed to prevent the eclosion of nauplii. As the actual temperature of the contained eggs was not determined, these experiments are not so definite as might be desired, but indicate that temperatures above 50° must have likely penetrated to the eggs.

Yellowstone National Park, Copeland ('36) has recently dealt with the temperature relations of this primitive group of plants. On the basis of extensive data collected in the field Copeland found that two species, belonging to different genera, *Phormidium bijahense* Copeland and *Oscillatoria filiformis* Copeland were both growing at a temperature of 85.2° C. This is the highest temperature at which any Myxophyceae were found and as the Yellowstone flora includes a larger number of forms in this group than any other hot springs area, it is probable that these records will not be exceeded in the future. They are indeed, practically identical with previous careful observations made by others and if they are to be exceeded the differences will certainly be negligible in amount. Copeland has not studied the bacteria specifically, but reports the occurrence of living bacteria in these waters at slightly higher temperatures of about 88° C. Thus there are found blue-green algae of several groups and certain unidentified thermophilous bacteria extending to temperatures of between 80° and 88°, figures also in close accord with those noted for bacteria by others.

Between these and other living organisms there is a very wide gap, of approximately 30° C. or more, since no temperatures of over 50°–52° C. have been reported as compatible with life for any animals or for plants other than the bacteria and blue-green algae.[1]

Thus, the more we know about the distribution of living organisms in thermal springs the clearer does it become that their tolerance of high temperatures is not a purely quantitative matter. We find blue-green algae occurring from the ordinary temperatures of ponds and streams over a continuous range to about 85° C. Other plants and animals of all kinds extend continuously in a similar way to about 52° C., but not beyond. With a large and constant gap between these maxima for the two groups of organisms we must admit the occurrence of at least two factors determining heat resistance.

On the basis of present knowledge, it is perhaps idle to speculate concerning the factors that may determine such consistently different reactions. However, at least two plausible theories have already been advanced. Zinsser ('31) dealing with bacteria has suggested that lethal temperatures for specific organisms are determined by the balance between metabolic reactions. As temperatures rise above an optimum, catabolic reactions come to increase more rapidly than anabolic ones and finally lead to death. The same suppositions have been made with reference to the cells of both animals and plants from time to time (Sachs, Höber '25). They have been critically discussed by Bělehrădek ('36) who believes and it seems with reason, that the rapidity of the heat effect is too great to allow time for the accumulation of the postulated toxic metabolic products. Again, we should not expect to find a general agreement in lethal temperatures among animals and some green plants, and a wide divergence between these and other green plants. With reference to the several parts of higher plants there seems to be little difference between the underground and aerial structures. Observations by the writer and others indicate that soil or water surrounding the roots may rise to a maximum of ± 50°–52.5° C. without lethal effect. Wallace and Clum ('37) found that 52.5° C. was the highest temperature to which the leaf tissue of *Verbascum* could rise without inducing irreversible changes that result in the death of the area so affected. They found further that 58°–60° C. regularly kills the leaves of several diverse flowering plants. Rather should there be some correlation between types of metabolism and extent of heat resistance and such obviously does not exist. This is similar to the idea advanced first by Winterstein ('02) of asphyxiation due to a similar unbalance. In its latter form this hypothesis evidently cannot account for the similarity among animals and green plants whose oxygen relations are quite exactly reversed. It might perhaps seem plausible in connection with thermal waters whose oxygen and carbon dioxide tension are both usually low. Both are, however, so highly variable that we cannot on any consistent basis relate them universally to constant phenomena of any kind.

Various workers since the time of Pasteur have noted and commented on the increased resistance shown by seeds and spores to high temperatures and have attempted to relate this to the fact that proteins in general coagulate at higher temperatures when desiccated than when well supplied with water. Assuming that an increased viscosity, disorganization, and coagulation of living protoplasm follow a similar course with reference to rising temperature, the failure of organisms to survive excessive heat has been attributed to irreversible changes in their actual living substance. Obviously, again the generalizations of such an hypothesis recognize no fundamentally different types of response among organisms although they necessarily grant much continuous variation as regards actual heat resistance since it is a matter of common knowledge that such exists.

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[1] As has been noted on another page, Tuxen ('36) has very recently reported the occurrence of certain insects in thermal springs in Iceland at temperatures as high as 65° C. These observations are so greatly at variance with those of many other workers in this field that they most certainly need careful repetition to make sure that actually living insects are concerned. This is especially true of insect larvae of the family Stratiomyiidae to which these records refer since the overflows in which they live are frequently subject to great temperature changes following sudden shifts in water currents.

Concerning all these suppositions there is a maze of experimental data relating to the killing of organisms by heat under practically every manner of conditions, both internal and external. From all this, there has unfortunately emerged no conclusive evidence, nor consensus of opinion as to how, or even whether, phenomena related to protein coagulation or denaturization are concerned.

There is also a mass of observations relating to changes in visible structures in chemically recognizable substances and even in "ultramicroscopical" constitution, of cells and tissues that have been subjected to lethal or near-lethal temperatures. These relate to a great variety of animals and plants and give a complicated picture, with certain features in common. One of these is the rather narrow temperature range at which such changes are quite consistently noted.

The appearance of visible granules has been noted in cells of Protozoa (Schultze '63), in algae (*Spirogyra*) by Lepeschkin ('10) and in other organisms, these appearing at temperatures usually near 45°. Similarly, vacuolization, cytolysis, and modifications of cell form and size are frequently noted at about the same temperature or slightly higher. Changes in the nucleus, commonly involving the chromosomes, are among the first visible cytological changes to occur in the cells of animals when subjected to temperatures above their biokinetic limits. These are to some extent reversible if the exposure to heat is not too prolonged. Thus during mitosis changes may occur resulting in asymetrical divisions or sometimes giving rise to abnormalities or polyploidy. Strangely enough the effect of heat, like that of the drug colchicine is most pronounced in arresting mitosis between the metaphase and telophase.[1]

Finally the visible effects of lethal temperatures are manifest in the mitochondria. I have dealt with these briefly in a previous paper (Brues '28) where the suggestion was made that these minute cytoplasmic objects might quite likely be immediately concerned in determining the upper temperature limits of life. The basis for this idea is the fact that the mitochondria (or chondriosomes) seem to be quite universally highly susceptible to heat, being usually destroyed or permanently damaged at temperatures of between 46°–52° C. They appear to be of regular occurrence in the cells of animals including the germ cells, and those of all except the lowest plants. That mitochondria occur in all animals cannot be definitely stated, but their presence is so widespread that there is no reason to doubt their universal occurrence. The same is true of the green plants that contain chloroplastids, in fact the plastids of such plants appear to owe their origin to mitochondria.

It has recently been questioned by Sorokin ('37) whether the mitochondria and plastids of the higher plants are really identical structures. Although both are extremely similar in appearance and are self-perpetuating by division, she has shown that they react differently in the living state to Janus green B, the plastids failing to take up this stain, although the mitochondria are stained readily. Since, however, the process of staining is to some extent dependent upon hydrogen ion concentration, her contention, although plausible, cannot be considered as finally proven. In any case the distinction between plastids and mitochondria does not indicate that they are in any sense fundamentally different structures, even though not identical.

Mitochondria have also been found in fungi. They do not occur, however, in the blue-green algae, which lack also chloroplastids and they are absent so far as is known in bacteria. The exact nature of the mitochondria is of course not well understood, mainly on account of their minute size, coupled with the fact that they are not demonstrated by popular methods of cytological study. That they are ever essential to life is sometimes questioned, but in the groups where they occur it is generally believed that they must play a definite role in metabolism, probably in cellular respiration or oxidation, at least in animals.[1]

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[1] cf. Kemp. & Juul, '31; Lambert & Hanes, '13; and many other papers cited by Bělehrădek '35.

In his paper on Myxophyceae, Copeland ('36) has raised the objection that temperatures lethal for some animals, *e.g.*, certain marine coelenterates and echinoderms, are much lower than those at which the mitochondria usually suffer irreversible changes. Such is most certainly correct and it is generally true that the heat susceptibility of marine animals is usually much greater than that of fresh-water and terrestrial forms. As a matter of fact among the long series of animals that occur in hot springs there is great variation among different forms and many certainly never extend into water above 30° or thereabouts. I certainly should not attempt to apply to such organisms any general theory concerning the deleterious effects of heat. Many of them are obviously handicapped by respiratory apparatus incapable of functioning at tensions of oxygen that are quite sufficient for other organisms. Again there are animals, *e.g.*, the primitive insect *Grylloblatta*, that normally lives at temperatures only slightly above freezing and succumbs when subjected to those necessary for the activity of related insects. Various "snow" insects are similar in this respect. Moreover, we have positive proof in at least one case that races of the same species may exhibit distinctly different maxima of heat tolerance. Banta and Wood ('28) have described a thermal race of cladoceran Crustacea which arose as a result of sexual reproduction in a strain of *Daphnia longispina* which Professor Banta had previously under continuous observation in the laboratory for fourteen years through 363 parthenogenetic generations. The normal temperature for growth and survival of these animals is ± 20° C. and they will not survive at 27° C. The thermal race arose as a mutation and shows optimum growth and survival at a temperature of 27° C., the lethal point for the parent stock. Rapid heating of the two races results in death at 38° for the normal stock and at 43° for the thermal one. The maximum growth temperatures are 26° and 32° respectively. It is perfectly obvious in this case that we are not dealing with any general characteristic of protoplasm, but with the appearance of a recessive mutation which showed itself after sexual reproduction and was later maintained through the succeeding parthenogenetic ones. In either case the heat resistance is not high, compared with many other arthropods, and can hardly be considered as having a direct bearing on the much higher critical point of ± 50° C.

It does appear, however, that the very consistent reactions of the most diverse animals and plants in approaching toward a narrow range of lethal temperatures is due to some fundamental peculiarity either in the constitution of their tissues or in the operation of their metabolic processes. So far the only recognizable difference between the two series, one approaching to ± 50° C. and the other to ± 85° C. is the presence of mitochondria in one and their absence in the other. Whether the mitochondria are metabolically active structures or whether they only indicate some type of metabolic function, such as oxidation, that is associated with their presence cannot be stated with assurance.

It may be argued that since nuclear changes commonly appear in the cells of animals when subjected to lethal or sublethal temperatures, that we must look to the nucleus for the susceptible structures. Such changes as have been observed in both animals and plants are by no means uniform but they occur experimentally at temperatures quite similar to those which affect the mitochondria. According to various observers they consist frequently in a visible disorganization of the nucleus sometimes associated with its fragmentation or coagulation and the disappearance of the contained chromatic substance. The blue-green algae lack nuclei also, so that they are in this respect different from animals and other plants. Concerning the bacteria it cannot be stated that they either possess or lack nuclei directly comparable with those of other organisms. They certainly contain substances which indicate the presence of some structural or physiological homologue of the differentiated nucleus. It is likewise difficult to say whether bacteria may contain mitochondria. So far as we know, they do not and I believe there is no evidence that we should attribute to them any homologous structures. If these latter statements represent correctly the status of the bacteria it is clear that it is the mitochondria and not the nucleus which form the structural difference between the types of organisms of high and low thermal resistance.

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[1] The literature on temperature and mitochondria has been briefly summarized by Bělehrădek ('35) and the reader will find other papers relating to them with reference to the present discussion cited in my 1928 paper, to which the following may be added as particularly relevant: Famin, '31; Heilbrunn, '28; Kemp & Juul, '31; Lewis & Lewis, '15; Polichard, '12; Polichard & Mangenot, '22; Schultze, '63; Winterstein, '02.

There remains the possibility that heat susceptibility is a general physiological phenomenon relating to protoplasm and metabolism as such and not associated with any definite structural constitution in the organisms concerned. The improbability of such a supposition is I believe clearly shown by the grouping of living organisms into the two quite clearly distinct categories having widely separated thresholds or ranges of heat susceptibility.

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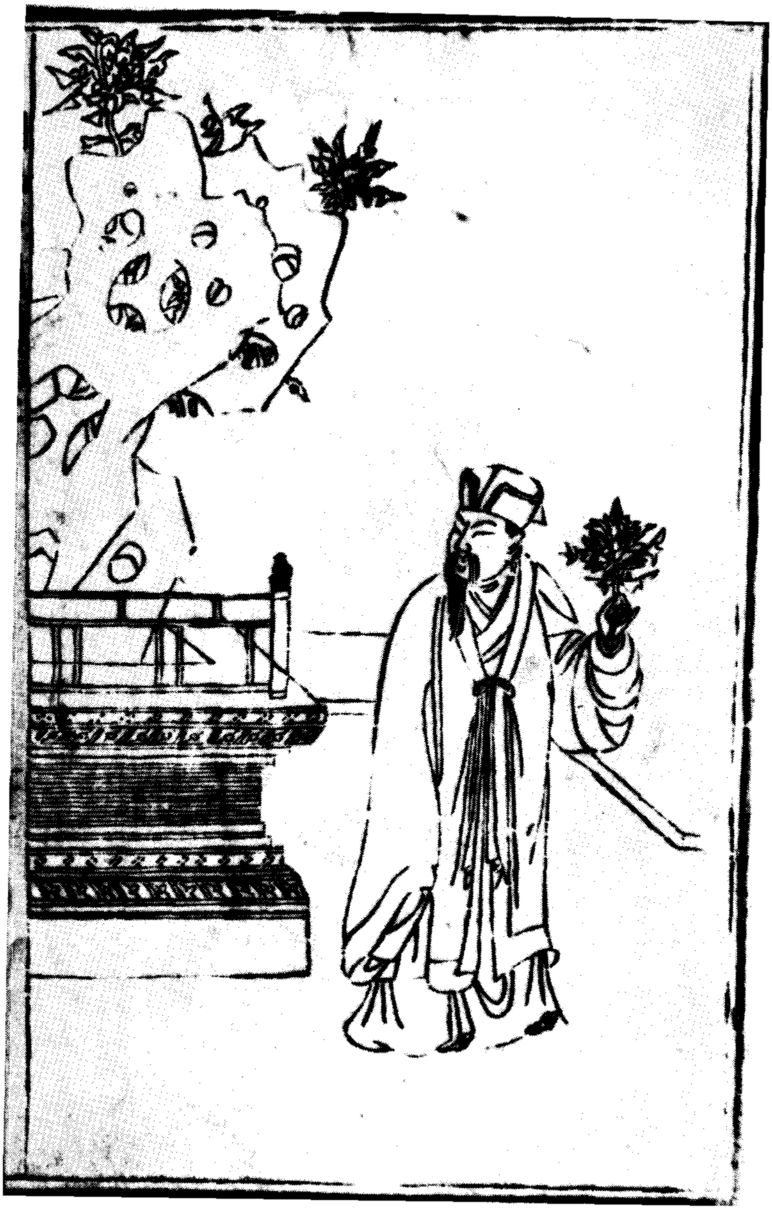

CHANG PO-TUAN

Picture reproduced from the *Lieh hsien ch'üan chuan*. In his hand the jade flower (*Hydrangea*) which he brought back from the spirit journey to *Yang-chou*.

CHANG PO-TUAN OF T'IEN-T'AI,

HIS WU CHÊN P'IEN, ESSAY ON THE UNDERSTANDING OF THE TRUTH

A Contribution to the Study of Chinese Alchemy

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Introduction

a.) The *Wu chên p'ien* 悟眞篇[1] (Essay on the Understanding of the Truth) of *Chang Po-tuan* 張伯端 was written more than nine hundred years later than the *Ts'an t'ung ch'i* 參同契[2] of *Wei Po-yang* 魏伯陽, which is the earliest known treatise on alchemy. It is however, an important classic, for later Chinese alchemists wrote commentaries upon it, and these same commentators wrote works on alchemy which, like the *Wu chên p'ien*, had wide circulation and influence. The present translation, by *Chao Yün-ts'ung* 趙雲從, represents, we believe, the second case in which a Chinese alchemical treatise has been translated *in extenso* into a European language.[3] *Chang Po-tuan* (983–1082 A. D.) was a contemporary of Avicenna (980–1037); there is no reason for supposing that the Chinese and the Arab were acquainted with one another's work, but the *Wu chên p'ien* supplies abundant new evidence in support of the opinion that the fundamental alchemical doctrine of the Chinese and of the Arabs and later Europeans was the same. It resembles the *Ts'an t'ung ch'i* in containing no practical chemistry. The fact that it deals with theoretical alchemy makes it of especial interest for the student of the history of the transmission of ideas. It maintains and amplifies the doctrine of the *Ts'an t'ung ch'i* by setting forth clearly a dualistic theory of alchemy. It resembles the earlier work in making use of the *kua* 卦 and the symbolism of the Book of Change, and in using Taoist language, but differs from it in showing the influence of Buddhism. It uses so many symbolic and metaphorical names for the two principles that it reminds one of the later European treatises on alchemy, say those of the seventeenth century, of such men as Count Michael Maier, Sendivogius, Eirenaeus Philalethes, and Samuel Norton who wrote not wholly for the purpose of expounding alchemical theory but rather in large part for the sake of the satisfaction which an artist derives from arranging his symbolism and imagery. The ninety-nine poems or songs of which the *Wu chên p'ien* consists are masterpieces of Chinese literary craftsmanship. All or certain ones of them, particularly those near the end of the Essay, were probably intended to be sung or chanted.

b.) The European alchemists wished to make gold from base metal, to prepare the Philosopher's Stone or transmutatory Powder of Projection, and in general were actuated by a desire for the gold itself because of its intrinsic value. The Elixir of Long Life or Universal Panacea, while a major objective, was commonly a secondary one. It was potable gold. Gold and the Philosopher's Stone alike were to be prepared by the interaction or combination of the two prime contrary principles, Sulfur and Mercury, masculine and feminine, positive and negative. The two were made to react by being heated together in a closed vessel, from which no material might escape, first with a gentle fire and then with a stronger one. The motives of the Chinese alchemists were different from those of the Europeans. They wished to prepare gold because of its magical efficacy. The eating of food out of vessels of gold, of real gold whether native or the product of the alchemical process, would confer longevity upon the eater. And the eating of gold itself, *chin tan* 金丹 (gold medicine), would convert the eater into a *hsien* 仙 or supernatural immortal endowed with extraordinary powers. But the alchemical process was the same. That which is described in the thirteenth century *Speculum Alchemiae* of the real or pseudo Roger Bacon is the same as that which *Wei Po-yang*, who called his principles *yin* 陰 and *yang* 陽, Moon and Sun, Tiger and Dragon, described in the second century in the *Ts'an t'ung ch'i*. *Chang Po-tuan* describes the same process, for example in the eighteenth poem of the *Wu chên p'ien*, where he says that the *wu* 烏 (crow) (representing the Sun or the positive principle) and the *t'u* 兎 (rabbit) (representing the Moon or the negative principle) are to be put together into the pot and treated as in cooking. "When you drive the two things into the yellow way, there is no reason why the Gold Medicine will not form."

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[1] For the romanization of Chinese words we have followed the spellings which are used in Giles' Chinese-English Dictionary, 2nd. ed., London, 1912. As this does not completely identify the words, we have printed the Chinese characters at the places of the first occurrence of the words. Later occurrences are indicated in the Index of Chinese Words. To facilitate indexing, the paragraphs of the Introduction are lettered alphabetically, a to z, then aa, ab, etc., and the poems of the translation are numbered. Chinese personal names are given in the Chinese manner, family name first.

[2] Translated by *Wu Lu-ch'iang* 吳魯強 with Introduction and Notes by Tenney L. Davis, *Isis*, *18*, 210–289 (1932).

[3] It is hoped that a fairly complete job on the Inner Chapters of *Pao-p'u-tzŭ* 抱扑子 will soon be finished. Inner Chapters 4 and 16, translated by *Wu-Lu-ch'iang*, have been published, *Proc. Amer. Acad. Arts and Sciences*, *70*, 221–284 (1935). A translation of Inner Chapters 8 and 11 by *Ch'ên Kuo-fu* 陳國符 is in manuscript, and it is hoped that it will be published in due course along with translations by the same hand of Inner Chapters 2 and 7 and the autobiography of their author together with Brief Summaries of the other Inner Chapters.

c.) After the nature of the two contrary principles had been established, the theory made clear and the process described, the alchemists turned their ingenuity, or a part of it, to the devising of synonyms, similes, symbolism, and imagery by which the two principles might be represented. The great similarity between Chinese and European alchemical symbolism has been pointed out,[4] and has been taken as confirmatory evidence of the identity of Chinese and European alchemical theory. The *Wu chên p'ien* supplies further evidence, for *Chang Po-tuan* uses many different names[5] and symbols to represent the two prime materials for the preparation of *Chin tan*. Some of these are tabulated below.

Yin	*Yang*
Moon	Sun
Tiger	Dragon
Mercury	Lead
Kua of *li* 離 (☲)	*Kua* of *k'an* 坎 (☵)
K'un 坤 (Earth)	*Ch'ien* 乾 (Heaven)
Pai hsüeh 白雪 (White Snow), *ch'i* 氣 (ethereal essence) of Tiger	*Huang ya* 黃芽 (Yellow Sprout), *ch'i* of Dragon
Ch'a nü 姹女 (Elegant Lady), the beloved bride, the true mercury of *li*, fluid of wood.	*Chin kung* 金公 (Golden Fellow), the aged husband, the true lead.
Quicksilver, *yin* substance, *ch'i* of Tiger	*Yü jui* 玉蘂 (Jade Bud) *yang* substance, *ch'i* of Dragon
T'u (rabbit); *shan* 蟾 (Toad)	*Wu* (Crow)
Shui 水 (Water)	*Chin* 金 (Metal)
Wood	Gold
Obedient	Compassionate
Internal	External
West	East
Host	Guest
Tortoise	Snake; Phoenix

The use of the term, lead, to designate the positive principle, suggests the possibility of a relationship between Chinese alchemy and Alexandrian chemistry, but the point is one which we wish to investigate more fully and to discuss at a later time.

d.) The *Lieh hsien ch'üan chuan* 列仙全傳 (Complete Biographies of the Immortals) contains a biography and a picture of *Chang Po-tuan*. Since the biography is a coherent and interesting story, even though it is a secondary account, we prefer to quote it first, and afterwards to discuss the material which is given in the gazetteers.

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[4] In a paper on "Pictorial Representations of Alchemical Theory," *Isis*, *28*, 73–86 (1938). In this paper a page from an alchemical text of *Ch'ên Chih-hsü* 陳致虛, otherwise *Ch'ên Kuan-wu* 陳觀吾 or *Shang-yang-tzŭ* 上陽子, is reproduced, a page which pictures a "Diagram of the Medicine-Laboratory of *Tzŭ-yang* 紫陽." The diagram is a table of contraries, from which fact it is inferred that the alchemical laboratory is the place where the contraries are brought together. We now know that the *Tzŭ-yang* in question is the same man as *Chang Po-tuan* to whom the present paper is devoted.

[5] There is confusion and apparent contradiction in the case of *nü tzŭ* 女子 (lady) who dresses in green and who, *Hsieh Tao-kuang* 薛道光 says, is the *ch'i* of Dragon (i. e. *yang*) and in the case of *lang chün* 郎君 (husband) who puts on mourning white and who, the same commentator states, is the *ch'i* of Tiger (i. e. *yin*) (Poem 17). *Lang chün* is elsewhere (Poem 86) represented as the essence of Gold (*yang*). *Hsieh Tao-kuang* also says that *lang chün* is *yang tan* 陽丹 and *Shang-yang-tzŭ* that it is the lead of *k'an* (*yang*).

e.) *Chang Po-tuan* was born at *T'ien-t'ai* 天台. When he was a young boy he loved study. When he was mature he was taught the *Tao* 道 of *hun yüan* 混元[6] (Mixed Elements) but did not yet understand it thoroughly. He sought for it very diligently, and made journeys in all directions. In the second year of the reign of *Hsi-ning* 熙寧 (1068–1078 A. D.) of the *Sung* 宋 dynasty, he travelled into *Ssŭ-ch'uan* 四川 and met a man named *Liu Hai-ch'an* 劉海蟾 by whom he was instructed in the secrets of the fire and the season for compounding *chin i huan tan* 金液還丹 (Gold Fluid Returned Medicine). He then changed his name to *P'ing-shu* 平叔 (Peaceful Younger) and assumed the title of *Tzŭ-yang* (Purple *Yang*). Meanwhile he met a monk named *Ting-hui* 定慧 who had been trained in the deepest doctrines of Buddhism. This monk was able to behave like a deity and to travel back and forth over a few hundred miles of distance in a few minutes of time. The monk became a sympathetic friend of *Tzŭ-yang*.

f.) One day *Tzŭ-yang* said to the monk: "Buddhist Teacher, can you take a journey with me to a far distance today?" The monk replied: "Yes." *Tzŭ-yang* said: "Where do you wish to go?" The monk answered: "I should like to go to *Yang-chou* 揚州 where we may enjoy the jade flowers."[7] *Tzŭ-yang* and the monk then went into a quiet room and sat down face to face with their eyes closed. After sitting Buddha-wise for a while, *Tzŭ-yang* arrived at *Yang-chou*—but the monk was there ahead of him. They walked around the flowers three times. *Tzŭ-yang* said: "Let us take a flower for a memento." Then each of them took a flower, and came back. After a while *Tzŭ-yang* and the Buddhist Teacher yawned and then awoke. *Tzŭ-yang* said: "Buddhist Teacher, where is your jade flower?" The Buddhist Teacher looked in his sleeve, and the sleeve was empty. However *Tzŭ-yang* took out his own jade flower from his sleeve, and enjoyed the flower with the monk.

g.) *Tzŭ-yang*'s disciples then asked him: "The Buddhist Teacher and our teacher went together on a spirit-journey. Why this difference that one has a flower and the other has not?" *Tzŭ-yang* replied: "When I learned my *chin tan* (gold medicine) Great *Tao*, I trained both in *hsing* 性 (nature of man) and in *ming* 命 (life). Therefore, when (the *Tao* is) gathered, it takes material form, and, when dispersed, it takes the form of *ch'i* (ethereal essence). Wherever I arrive, since I am a genuine spirit, I take a visible material form. This is known as the spirit of *yang*. The monk's training sought to attain the effect quickly: he did not learn the *ming*. Therefore, wherever he goes, men cannot see his material form or his shadow. This is known as the spirit of *yin*. The *yin* spirit cannot move material things.

h.) In the reign of *Ying-tsung* 英宗 (1064–1068 A. D.) (*Sung* dynasty) he followed *Lung-t'u-lu-kung* 龍圖陸公 to live at *Kuei-lin* 桂林. Later he wandered to *Ch'in-lung* 秦隴. Still later he visited *Ma Mo Ch'u-hou* 馬默處厚 at *Ho-tung* 河東. At this time he gave *Ch'u-hou* 處厚 his writing, *Wu chên p'ien*, and said: "The learning of my life is here. I hope that you will be able to circulate the book. Someone will make use of it, and understand its meaning."

i.) In the summertime of the fifth year of the reign of *Yüan-fêng* 元豐 (1078–1086 A. D.), he sat himself down Buddha-wise, and died at the age of ninety-nine years. His disciples burned the body, and obtained thousands of *shê li* 舍利 (relics). The larger ones were as large as water-chestnuts, and had a jade-green color. People who knew these things said: "These are the *shê li* which are called as beautiful as gold."

j.) Seven years later, *Liu Fêng-chên* 劉奉眞 met *Tzŭ-yang* who came out from *Wang-wu* 王屋 (*Wang*'s House, name of a mountain). *Tzŭ-yang* left a stanza of poetry, and then went away. *Tzŭ-yang* had said that *Huang Mien-chung* 黃勉仲, *Wei Yang-yü* 維揚于 and he himself were stars of *Tzŭ-wei* 紫微 (a star god invoked when building), acquiring the title of *Chiu-huang-chên-jên* 九皇眞人 (True Men of the Ninth Kingdom) (Very Almighty True Men) because they made mistakes in proof-reading certain books, so that they are banished to the human world. Now in the city the stars which are seen brightly luminous are the six stars.

k.) With the kind assistance of *Dr. Hsü Chia-lin* 徐家麟 Librarian of the Harvard Yenching Institute, we have been able to find further information about *Chang Po-tuan* in the county and provincial records.*

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[6] *Hsieh Tao-kuang* says: "There was something formed by mixing before the heaven and the earth. This thing has been put into words constrainedly and is known as the *Tao* of *hun yüan*.

[7] Jade flowers, *ch'iung hua* 瓊花, a kind of *Hortensia* (i. e. *Hydrangea*) said to confer immortality if eaten.

* *Chê-chiang t'ung chih* 浙江通志 (General Record of *Chê-chiang* Province), *chüan* 卷 200, section *hsien* and Buddhist, part *T'ai-chou fu* 台州府, written between the ninth and thirteenth years of the *Yung-chêng* 雍正 reign (1723–1736) by *Chi Tsêng-yün* 稽曾筠 and others. *T'ai-chou fu chih* 台州府志 (Record of the District of *T'ai-chou*), *chüan* 100, section *fang wai* 方外, written during the *Kuang-hsü* 光緒 reign (1875–1908) by *Wang Chou-yao* 王舟瑤 and others. *Ssŭ-ch'uan t'ung chih* 四川通志 (General Record of *Ssŭ-ch'uan* Province), *chüan* 167, section *hsien* and Buddhist, part *Ch'êng-tu* 成都, written between the seventeenth and nineteenth years of the *Chia-ch'ing* 嘉慶 reign (1796–1821) by *Li Luan-hsüan* 李鑾宣 and others. *Shan-hsi t'ung chih* 山西通志 (General Record of *Shansi* Province), *chüan* 160, section *fang*

l.) The county city of *T'ien-t'ai* is situated about 150 kilometers southeast of *Hang-chou* 杭州 (*Hangchow*), the capital of *Chê-chiang* 浙江 province, near the coast of China. The famous *T'ien-t'ai* mountain is northeast of the city. About thirty kilometers south of *T'ien-t'ai* city is the county city of *Lin-hai*, the old name of which was *T'ai-chou*, the county city of *T'ai-chou-fu* (the District of *T'ai-chou*) of which District *T'ien-t'ai* was once a part.

m.) The *Chê'chiang t'ung chih* (General Record of *Chê-chiang* Province) states that *Chang Po-tuan*, *P'ing shu*, acquired the title of *Tzŭ-yang*, that he was born at *T'ai-chou*, and that he met *Liu Hai-ch'an* by whom he was instructed in the method of *chin tan*. It says that he wrote down all that he knew in the *Wu chên p'ien*, but does not mention any other of his writings. The General Record of *Chê-chiang* Province and the *Shan-hsi t'ung chih* (General Record of *Shensi Province*) both repeat the whole story of the spirit-journey with the Buddhist monk, in language identical with that of the *Lieh hsien ch'üan chuan*, and state that *Chang Po-tuan* died in the fifth year of *Yüan-fêng* at the age of ninety nine years.

n.) The General Record of *Chê-chiang* Province further states that the County Record of *Lin-hai* tells that *Chang Po-tuan* was a citizen of the district, that he had another name *P'ing-shu*, and that he was for a time magistrate or administrative officer of the district. He liked to eat fish. When he was employed in his office, his food was sent to him from his home. His colleagues one day hid his fish in the upper part of the room. *P'ing-shu* suspected that it has been stolen by the maid, and went back to beat her. The maid, terrified, killed herself. Later, a worm dropped down from the rafters. *P'ing-shu* examined it, and found that it had come from decayed fish. He then regretted the matter deeply, and said: "My documents concerning law cases have filled all of the boxes; yet I do not know how many of these cases may be like that of the stolen fish." He wrote a poem, as follows, and burned up all of his law papers.

> o.) I have written on my law papers for many decades. The cases in which right seems wrong and wrong seems right have been thousands of thousands. Moreover, when one family keeps warm and has enough to eat, there must be hundreds of families which are left in want. Half a life of high rank makes enmity for generations. From now on, the golden seal tied with purple ribbon is finished (for me). I must again wear my straw slippers and use my bamboo stick—and let my life pass happily. If anyone chooses to ask me the way to *P'êng-lai* 蓬萊, I shall reply to him that it is the clouds on the blue mountains and the moon in the sky.

p.) He was found guilty of burning the documents, and was exiled. In exile he met a man who was addicted to the eating of salt, and often ate ten catties at one time. *P'ing-shu* served this man faithfully. When they separated, the man said to *Po-tuan* 伯端: "Whenever you meet misfortune, shout three times 'My teacher!', 'My teacher!', 'My teacher!'; then your misfortune will disappear." Later he visited the spring, *Pai-pu-chi* 百步溪 (Hundred Steps Spring) on the mountain, *Pai-pu-ling* 百步嶺. The weather was hot; he washed himself—and went away to *hsien*. Later a temple of *Tzŭ-yang-chên-jên* was built on *Pai-pu-ling*, a sign at the gate saying that it was "The place where *Tzŭ-yang* became a *hsien*." The story that *Chang Po-tuan* became a *hsien* is reported in the portion of the Provincial Record which relates to *hsien*. The historian states that its truth has been debated.

q.) The *Shan-hsi t'ung chih* 山西通志 (General Record of *Shan-hsi* Province) reports the same story as the *Lieh hsien ch'üan chuan*, but in an abbreviated form, and omits the story of the Buddhist monk and the spirit journey.

r.) The *T'ai-chou fu chih* (Record of the District of *T'ai-chou*) appears to contain the most reliable story written by the best historian. It states that *Chang Po-tuan* was born at *T'ai-chou*, that he had another name, *P'ing-shu*, and acquired the title *Tzŭ-yang*, that he visited *Ch'êng-tu* the capital of *Ssŭ-ch'uan*, and met *Liu Hai-ch'an*

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wai, part 1, written in the eighteenth year of the *Kuang-hsü* reign by *Chang Hsü* 張煦 and others. *Ssŭ k'u ch'üan shu tsung mu t'i yao* 四庫全書總目提要 (Abstract of the Comprehensive Treatise on Books of the Four Cabinets), written in 1782 by *Chi Yün* 紀昀 and others, contains an account of *Chang Po-tuan* and an evaluation of the *Wu chên p'ien* in division *tzŭ* 子, subdivision 56, part Taoists, vol. 146. The great encyclopedia, *Ku chin t'u shu chi ch'êng* 古今圖書集成 compiled by *Chiang T'ing-hsi* 蔣廷錫 and a committee of scholars under the personal supervision of the Emperor *K'ang-hsi* 康熙 (1662–1722) contains in division *po wu hui p'ien* 博物彙篇, sub-division *chên i tien* 神異典, *chüan* 252, section *shên hsien* 神仙, subsection *lieh ch'uan* 列傳, part 29, *Sung* 1, material on *Chang Po-tuan* from the County Record of *Lin-hai* 臨海 and from the General Records of *Shan-hsi* 山西 and *Shan-hsi* 陝西 (*Shensi*) Provinces.

from whom he learned the method of compounding *tan* 丹. He wrote all that he learned of the secret in eighty-one poems (we find ninety-nine) entitled *Wu chên p'ien*—this from the record of the city of *Ch'ih-ch'êng* 赤城 which is near *T'ai-chou*—and gave the book to *Ma Mo Ch'u-hou* of *Fu-fêng* 扶風 (a city of *Shensi* Province) saying: "The learning of all of my life is here." Later generations regard the book as "one of the books of the Taoist ancestors." *Chang Po-tuan* died at the age of ninety-nine years. Afterwards a temple of *Tzŭ-yang-chên-jên* was built on *Pai-pu-ling*, and a School of *hsien* of *T'ien-t'ai* flourished there, followers of his teaching.

s.) An extra note written by the same historian is as follows. "It is stated in the County Record of *Lin-hai* that *Po-tuan* encountered an incident. Because of his eating fish, he made a mistake on his maid, and the maid died of it. He was found guilty and went to *hsien* at *Pai-pu-ch'i*. This account does not agree with that recorded in the Record of the City of *Ch'ih-ch'êng* and is not found in *Fang wai chih* 方外志 (Local Extra Record). I suspect that this story is not the actual fact but was so recorded merely on the rumors of the local vulgarians, and for that reason I do not dare to copy it here."

t.) The *Wu chên p'ien* is discussed in the *Ssŭ k'u ch'üan shu tsung mu t'i yao* (Abstract of the Comprehensive Treatise on Books of the Four Cabinets), written in 1782 by *Chi yün* and others, in a manner which is of especial interest to us because it shows how the Chinese have evaluated the book.

u.) The *Wu chên p'ien* was written by *Chang Po-tuan* of the *Sung* and was commented upon by *Wêng Pao-kuang* 翁葆光 and *Tai ch'i-tsung* 戴起宗 (as in our *Ming* 明 edition described below). *Po-tuan* had another name *P'ing-shu*. He was born at *T'ien-t'ai*. He himself says that he was in *Ssŭ-ch'uan* during the *Hsi-ning* reign, where he met a stranger who taught him the secret of *tan*. He died at *Chin-hu* 荊湖 during the reign of *Yüan-fêng*. The common people say that he became a *hsien*.

v.) This book describes the essentials of *chin tan* and is considered as important as the *Ts'an t'ung ch'i* as one of the real ancestors of Taoism. The book says that one must know the sources of the native medicines. The direction for seeking them is in the southwest of your town (cf. Poem No. 7.). The ideas are like those of the *Ts'an t'ung ch'i* that things which are produced in three days are *hsün* 巽 (a *kua*). *Chên* 震 (a *kua*) grows in the direction west of *kêng* 庚 (a symbolic number). The book says that in case the whole contents weighs one catty, then each component should be one half of a catty (No. 7.). This resembles the statement in the *Ts'an t'ung ch'i* that the *t'ui* 兌 (a *kua*) of the first part is eight and the *kên* 艮 (a *kua*) of the last part is also eight. The book says that three, five and one are written only with three numbers the meaning of which has been understood rarely by workers whether of ancient or of recent times (No. 14). This is like the statement in the *Ts'an t'ung ch'i* that three, five and one are the supreme essentials of heaven and earth, and may be imparted by oral instruction but cannot be written on paper. The book says that fire is produced from wood, the inflammability of which however, is hidden, and that to overcome this difficulty it is advised to seek for *chin kung* (No. 41). It resembles the *Ts'an t'ung ch'i* in teaching that *ho ch'ê* 河車 (river car) and *ch'a nü* (elegant lady), when they possess fire, will fly. If one wishes to control them, *huang ya* (yellow sprout) supplies the means. The rest of the work is also interpreted correspondingly.

w.) When the book began to be known by the people, the Taoists transmitted it from hand to hand but the Confucianists practically never gave instruction in it. During the reign of *Ch'ien-tao* 乾道 (1165–1174 A. D.), *Wêng Pao-kuang* wrote the first commentary, and divided the work into three parts. At a later time *Wêng*'s commentary[8] was erroneously supposed to have been written by *Hsieh Tao-kuang*, and *Wêng*'s name was accordingly suppressed. During the reign of *Chih-shun* 至順 (1330–1333 A. D.), *Tai Ch'i-tsung*[9] got the old book, restored *Wêng*'s name to *Wêng*'s commentaries, and himself wrote another commentary on the work.[10] It has never been heard that these two men became as light as feathers and ascended to the sky.

x.) We have worked with two editions of the *Wu chên p'ien*. The earlier *Ming* edition with commentaries by *Tai Ch'i-tsung* and *Wêng Pao-kuang* comprises three volumes of a twenty-four volume collection of works on alchemy, *Chin tan chêng li ta ch'üan* 金丹正理大全 (Comprehensive Account of the Genuine Preparation of the Gold Medicine) printed during the reign of the *Ming* Emperor *Ying-tsung* 英宗 with the reign title *Chêng-t'ung* 正統 (1436–1450 A. D.). In this edition the text is accompanied by an author's preface dated the year of *i mao* 乙卯 of the reign of *Hsi-ning* (1068–1078 A. D.) of the *Sung* dynasty, "written by *Chang Po-tuan P'ing-shu* of *T'ien t'ai*." The later *Ch'ing* edition comprises three volumes printed in the fifteenth year of *Ch'ien-lung* 乾隆 (1736–1796 A. D.), hence 1750 A. D. The text is accompanied by the commentaries of *Hsieh Tao-kuang, Lu Shu* 陸墅 otherwise *Tzŭ-yeh* 子野 and *Shang-yang-tzŭ*, and by two author's prefaces, the first of which is identical with the preface of the *Ming* edition. The second, and more interesting, of the prefaces has been translated in full, as follows:

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[8] *Wêng Pao-kuang* was also named *Yüan-ming* 淵明 and had the title *Wu-ming-tzŭ* 無名子. He was born at *Hsiang-ch'uan* 象川.

[9] *Tai Ch'i-tsung*, also named *T'ung-fu* 同甫 was born at *Chi-ch'ing-lu* 集慶路. He was a Confucian teacher and at one time administrative officer of *Shao-hsing* 紹興 in *Chê-chiang* Province.

[10] One of the prefaces of our *Ch'ing* 清 edition emphasizes the fact that *Hsieh Tao-kuang*'s commentaries were mistaken for *Wêng*'s commentaries.

y.) I feel that a man is born into this world because of an error by which he acquires his body. Since he has his body, he then encounters misfortunes. If he did not have his material body, how could misfortunes affect him? Whenever a man wishes to avoid misfortune he ought to embrace the supreme *Tao*. If he wishes to embrace the supreme *Tao*, he ought to understand clearly *pên hsin* 本心 (original moral nature). Therefore, *hsin* 心 is the entity (being) of *Tao*, and *Tao* is the embodiment of *hsin*. When a man is able to observe *hsing* 性 (nature of man) and to understand *hsin*, then the perfect round and shining body will appear naturally. The use of *wu wei* 無爲 (not-doing) will succeed naturally. He will not need to consume his energies, but will pass over to the other bank immediately. If he does not possess a shining mirror of *hsin* and a clear wonderful pearl (i. e. manner, expression, appearance), how then can he separate promptly all of the faces without touching them with the least particle of dust?—and how can he retain the germinating power of *Hsin?*—and how can he know the matter of *wu shêng* 無生 (non-living)?

z.) Moreover, those persons who apprehend and attain *Tao*—their bodies will not involve their *hsing* to disadvantage. Their circumstances will not confuse their truth. How then can they be hurt by swords and weapons, by a tiger or a rhinoceros, by fire or flood? A clever man's *hsin* resembles a shining mirror which reflects but does not retain the light. He is able to make changes according to the environment, to keep in tune but not to sing himself. Therefore, he can overcome material things without damage to himself. This is the so-called wonderful *Tao* of the unexcelled and supreme truth.

aa.) Originally, *Tao* had no name. The sages named it artificially. Originally, *Tao* had no word. The sages put it into a word artificially. Consequently, the name and the word resemble silence. Hence, the common people cannot apprehend its being, and themselves be led to the truth. Therefore, the sages have created the teaching and built up words in order to make the *Tao* manifest. Hence, *Tao* is made manifest by words, and words are forgotten by *Tao*.

ab.) Alas, this *Tao* is most perfect and most subtle. The common people are not intelligent enough. They hold to their material bodies, and desire to live, and are afraid to die. Finally, they have difficulty in understanding. *Huang-ti* 黃帝 and *Lao-tzŭ* 老子 took pity on their incompetence, and accordingly gave them the secret of long life in order to satisfy their wants and to develop them gradually.

ac.) I know that the essential of long life is *chin tan*, and the essentials of *chin tan* are *shên shui* 神水 (spiritual water) and *hua ch'ih* 華池 (beautiful pond). Therefore the teachings of *Tao tê* 道德 (Way of Virtue) and of *Yin fu* 陰符 (Amulets of *Yin*) are able to diffuse throughout the world. Presumably the people want to live, but the words are obscure and the principle is difficult. Even though the disciples read the writings, yet they do not comprehend the meaning. If they do not meet a *chih jên* 至人 (supreme man) to instruct them orally in the secret, I suppose that they will make hundreds of guesses: they will not in the end be able to achieve the matter and prove its efficacy. Is it not like this: that the number of disciples is like the number of the hairs of a horse, while the successful achievers are as scarce as unicorns?

ad.) *Po-tuan* (the author) (on a certain date) visited *Ch'êng-tu* (the capital of *Ssŭ-chuan*) and met a teacher by whom he was taught the method of compounding *tan*. In the same year the teacher had a breakdown. Afterwards, he (*Po-tuan*) three times gave instruction to people, and three times he suffered misfortune—all within twenty days. Thereupon, he remembered his teacher's warning that whoever should loose his bridle and lock was to be given instruction; to others it was not permissible to give it. Afterwards, he (*Po-tuan*) wished to write commentaries on famous books, but he feared that the followers of *Tao* would not believe him. Consequently, he wrote this *Wu chên p'ien*, describing *tan* medicine from beginning to end. After he had finished this book, disciples rapidly gathered about him. He recognized their earnestness, and permitted no concealment of the secret. Accordingly, he selected his subject and instructed them in it. However, the disciples whom he was teaching were not persons of great social rank or of influence by which they could save one from danger or from sinking to the bottom; nor were they successful in life, nor able to practice benevolence and understand *Tao*.

ae.) Formerly he (*Po-tuan*) suffered again and again from misfortune, but he did not recognize it until the third time. He then regretted his earlier errors. He knew that the secret of the great *tan* is the simplest and the easiest, even though stupid common people were able to acquire it and to practice it, and by means of it were able to penetrate to the place of the sages. Therefore, the will of heaven loved the secret and did not permit it to be taught to those who were not the right ones. However, *Po-tuan* did not heed the words of the teacher and repeatedly disclosed the secret. Having his material body, he frequently encountered calamities for that reason. This was a severe punishment from heaven which arrived promptly. He said: "Should I not be afraid and control myself? From this time onward, I must keep my mouth closed and my tongue motionless, even though a *ting* 鼎 and a kettle (punishment with hot oil) are before me, or a sword is upon my neck. I shall not dare to blab again."

af.) The *Wu chên p'ien* sings of the great *tan* and the medicine, and describes the details of the fire and the season. Nothing is omitted. Those who love the art and have in their bones the qualities of *hsien* will read it and will themselves find it intelligible. They will find the meaning in the writing if they examine it critically. This will be as good as oral instruction from *Po-tuan*. Moreover, this book is a gift from heaven and is not alone the private instruction of *Po-tuan*.

ag.) At the end of the Essay he (*Po-tuan*) sings and chants about the *fa* 法 (method, technique, Buddhist practice) of seeing *hsing*. This is the so-called *Tao* of *wu wei* and *miao chiao* 妙覺 (super-sense, wonderful awakening). Moreover, the *Tao* of *wu wei*, which regards the equalizing of things as *hsin*, does not hold it a serious error if a secret is disclosed. Why do the common people who are sometimes rich in endowments and sometimes poor, who are sometimes intelligent and sometimes stupid, hear a single note and then confuse it into different tunes? Therefore, when the Buddha demonstrated his divinity, that was only one degree (degree of rank among scholars). Those who have heard of this explain it in many ways and make it a matter of three degrees. Anyone who has a keen mind and who reads this Essay will know that *Po-tuan* has acquired the highest degree from the sixth in line from *Ta-mo* 達磨 (a Buddha) and has been able to understand thousands of *fa* from hearing a single sentence. If the reader still retains the mental attitude of a common person and has only mediocre knowledge, that is not the fault of *Po-tuan*.

ah.) The date is in the year *wu wu* 戊午 (1078 A. D.) of the reign of *Yüan-fêng* (1078–1086 A. D.), the second month of summer, the day of *wu yin* 戊寅. Written by *Chang Po-tuan P'ing-shu*.

ai.) In addition to the *Wu chên p'ien* we have at hand two other works ascribed to *Chang Po-tuan*, namely *Yü ch'ing chin ssŭ ch'ing hua pi wên chin pao nei lien tan chüeh* 玉清金笥青華秘文金寶內鍊丹訣 (The Secret of Compounding Internal *Tan* from the Secret Papers in the Golden Clear Jade Box of *Ch'ing Hua*), 3 vols., *Ming* printing (probably not the work of *Chang Po-tuan*) and *Chin tan ssŭ pai tzŭ* 金丹四百字 (Four Hundred Word *Chin Tan*), 1 vol., the text of *Chang Po-tuan* with the commentaries of one writer in our *Ming* edition and of one writer and two disciples in our *Ch'ing* edition). Neither of these works is mentioned in the official histories which we have consulted. But the second appears to be genuine. We hope to report upon it more fully at a later time.

aj.) The translation of the *Wu chên p'ien* and of the other material from the Chinese is the work of *Chao Yün-ts'ung*. We have gone over it together word by word, and have taken every pains to make the translation as literal as possible. We have discussed all points together, and each of us has profited by the advice and suggestions of the other. We are grateful to Professor James R. Ware of Harvard University for reading the manuscript, for helpful suggestions, and for procuring the use of the Chinese type.

TRANSLATION

PART I

POEMS OF FOUR RHYMES

Sixteen Poems to Serve as Criteria for Two-Eight, Making a Catty[1]

1. If one does not seek after the great *Tao* (Way) in order to release himself from the wrong mode of life, he will finally lose his chance of possessing the talent—and is not to be regarded as a wise man. A hundred years of living is but a transient moment, the length of which resembles only a spark struck from a stone. The fate of life is like a bubble floating on water. Those who know nothing but income, emolument, fame, and rank will soon see their faces turning pale and their bodies degenerating. I suppose that the gain of money is capable of filling the valleys; however this non-permanent possession cannot purchase the things which do not come back.

2. Although life at best has a period of a hundred years, there is not a single known method by which one may be able to anticipate or to control his fate for a long or for an untimely end, for happiness or for suffering. (For example,) a man was actually riding on horseback yesterday, and this morning he is laid in his coffin. The beautiful wife and the possessions which he left are now no longer his, but the evil (which he did to get his possessions) will not permit him to be overlooked. The great medicines which await the search will not search for you. If you have them in hand and do not work at compounding them, you are merely ignorant.

3. If you are learning to be a *hsien* (immortal), you should learn to be a heavenly *hsien*. The most accurate means (for the purpose) is *chin tan*

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[1] "Two-Eight Making a Catty" as sixteen ounces makes up a Chinese pound.

(gold medicine). The two things, when put into contact with each other, will indicate harmonious properties. The Tiger and the Dragon locate at the places where the *wu hsing* 五行 (five elements) are perfected. I desire to send *wu ssŭ* 戊巳 as a matchmaker to make them husband and wife and to bring them into a union from which real happiness will arise. Wait for the success of the compounding, and you will return to see the north gate of the Imperial palace. You will be able to ride on a phoenix's back, to fly high into the cloud and the light of the sky.

4. This method is very, very efficacious and true because it is developed according to a new idea of my own which is different from that of others. I know that topsy-turvy-ness is caused by *li* and *k'an*.[2] Moreover, who can tell which portion will float and which portion will sink, which will be the host and which will be the guest? When we wish to detain (fix) mercury of red (cinnabar?) in the golden *ting* (tripod, furnace), we must first put the silver of water (quicksilver?) into the *yü ch'ih* 玉池 (jade pond). The wonderfully effective management of the fire will not be (completed) in a single morning. A wheel of moon will appear in the deep gulf.

5. The Tiger is dancing, the Dragon is flying, the wind roars and the storm rages violently. The mysterious pearl forms in the favored central position. It is like the ripening of fruit on the tree and the birth of the foetus from the womb, for the former is certain to ripen and the latter certain to be born. (This has been agreed) by all authorities, both of the North and of the South, and of the *kua* and of the *hsiang* 象 (the lines which compose the *kua*). The fire and the season are to be maintained day and night so that they will conform to the principle of heaven. It is known that the great work can be carried out in cities, and that it is unnecessary to watch over solitude in large mountains.

6. Everyone has a chance of getting the medicine of long life, but unfortunately most people are unintelligent and allow the medicine to be wasted. *Kan lu* 甘露 (sweet dew) is produced by the combination of heaven and earth, and *huang ya* (yellow sprout) is formed by the interlocking of *k'an* and *li*. Frogs, living in a well, can never see the abode of dragons high in the sky; orioles, flying so low, know nothing about the nests of phoenixes; (and people who are short-sighted will never see the medicines). *Tan* when ripened will give a man plenty of gold. One need not then pay too much attention to such matters as the cutting of wood or the burning of grass (for the cooking of food).

7. One must know the sources of the native medicines. The direction for seeking them is in the southwest of your town. Lead will form at the hour of *kuei shêng* 癸生 (belong-to-growth), and it should be collected as soon as it has just appeared. Gold at the hour of *wang yüan* 望遠 (after-the-full-moon) (long exposed) becomes worthless and cannot be tasted at all. (When you have procured the right lead,) put it into an earthen crucible, close the latter tightly and then add to it the proper proportion of *liu chu* 流珠 (flowing pearl) (mercury?). (In case) the whole contents weighs one catty, then each component should be one half of a catty. The fire and the season are regulated according to the principle of *yin* and *yang*.

8. Do not compound the Three Yellows and the Four Spirits.[3] Medicines of vegetable origin are still more different from the real medicines. *Yin* and *yang*, when they are of the same sort, will interlock with each other. Two-eight, the right proportion, will arouse naturally the affinity (of the constituents). At the moment when *yin* is exhausted, the body which resembles the red (image) of the sun in the bottom of a pond will appear. This will be the new sprout of the medicine and will turn into a color as white as the moon. Our fellow-workers must be able to recognize the true lead and mercury, which are neither common cinnabar nor mercury.

9. Medical preparations which are built up with *yin* inside of *yang* are not permanent. A man's achievements will turn out but lean if he works on a single substance. All busy, bustling, and stirring lives are antagonistic to *Tao*. It is crazy to take doses of the *ch'i* (ethereal essence) or of mist. The whole world wants to eat the lead and mercury (medicines); but when shall we see the arrival of the Tiger and the Dragon? I suggest that you should investigate thoroughly the immaterial origin of life. The substance which enables you to return to the origin and go back to the initial state is the king of medicines.

10. If you wish to search intensively for the

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[2] *Li* and *k'an* are two of the *kua* or magic figures of the Book of Change 易經. *Li* symbolizes *yin* (negative) and *k'an*, *yang* (positive).

[3] The commentator, *Shang-yang-tzŭ*, states that the Three Yellows are sulfur, orpiment, and realgar, and the Four Spirits alum, cinnabar, lead, and mercury.

true lead, do not allow your time to pass easily by. Capture the red mercury with the soul of the earth; then there will appear naturally the soul of heaven for controlling the *shui chin* 水金 (watery gold). It is known that the Tiger and the Dragon will surrender to the highly learned *Tao.* One can say that devils and spirits can be made to venerate you because of your glorious virtue. After you know that your life is as long as heaven and earth, then nothing of sorrow will come into your mind.

11. *Huang ya* (yellow sprout) and *pai hsüeh* (white snow) are not difficult to find.[4] A clever man who is likely to succeed ought to have a high moral purpose as his basis. The four signs[5] and the five elements depend primarily upon earth (the matchmaker). The three principles and the eight *kua*[6] go hand in hand (with the true single *ch'i* (ethereal essence)). The efficacious pills which they form can destroy all the devils of the *yin* region and can prevent attacks by ghosts, yet these accomplishments are hardly recognized by people. I desire to leave the secret of performing them to the human world; however, I have so far never met a man who appreciates my subject.

12. In the vegetable world grass and trees are also actuated by *yin* and *yang.* They could not grow in the absence of either one of these two forces. At the beginning, *yang* dominates and is indicated by the budding of green leaves. Then, after the development of blossoms, *yin* (destructive) follows. This principle of the *Tao* of constancy has long been the common practice of nature; but how many can understand (the principle of) *chên yüan* 眞源 (true spring),[7] which can alter this process (of nature)? I advise all of you, who wish to learn *Tao,* not to begin your work before you understand the principle of *yin* and *yang.*

13. If one cannot realize the topsy-turvy-ness and topsy-turvy-ness again of the technique of *hsüan* 玄 (mysterious), how can he understand that it is possible to cultivate lotus flowers in an atmosphere of fire? Bring the White Tiger back home whereby it is fed. A glittering pearl will be born which has a shape as round as the moon. Watch with care the fire and the season of the medicinal pot, and let whatever happens occur naturally and without hurry. The *tan* will ripen at the moment when all of the *yin* is eliminated—and (by this achievement a man) can escape out of the cage (of death) with a life of ten thousand years.

14. Three, five and one[8] are written only with three numbers the meaning of which has been understood rarely by workers whether of ancient or of recent times. Three in the east and two in the south make five; one in the north and four in the west give the same number. In the location of *wu ssŭ* there appear a few fives. *Ying êrh* 嬰兒 (the infant), the only one which consists of the true *ch'i* (ethereal essence), will be produced by the contact of the three families. After ten months of gestation, the womb ripens and (it) is able to penetrate to the place of the sages.

15. If one does not know the real ancestor of the true lead, his work will always be wrong no matter how much he has done. It is of no use for a man to abandon his wife and to starve himself (for the purpose of learning *hsien*) because *yin* and *yang* (the interlocking of which gives *tan*) are still separated. Grass, trees, gold, silver, and so forth are all residual material things. Clouds, mist, the sun and the moon only obscure the view. I suppose that you can also practice both "breathing" and "thinking" (in order to acquire *Tao*). All these necessarily differ from the affairs of *chin tan.*

16. The statement that *chin tan* is the most fundamental will be found to be identically set down in actual thousands of volumes of Books of *hsien.* As a rule, the bodies produced at the *k'un* position will be moved into the inter-influential chamber of the family of *ch'ien.* It is not to be wondered at that the secret of heaven has been entirely disclosed here, but the followers (who fail to get the secret) confuse themselves. If anyone understands the idea of these poems, he will at once see *Tai-shang-wêng* 太上翁 (the greatest of the *hsien*) at the place of *San-ch'ing* 三清 (Three Clear).

17. The *nü tzŭ* (lady) dresses in green whereas

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[4] The commentator, *Hsieh Tao-kuang,* states that *huang ya* is the *ch'i* (ethereal essence) of the Dragon and *pai hsüeh* that of the Tiger.

[5] According to the same commentator the four signs are wood, fire, gold, and water.

[6] According to *Hsieh Tao-kuang* the three principles are Dragon, Tiger, and *tan,* and the eight *kua* are *ch'ien* 乾 which stands for father, *k'un* 坤 for mother, *chên* 震 for the first son, *k'an* 坎 for the second son, *kên* 艮 for the youngest son, *hsün* 巽 for the first daughter, *li* 離 for the second daughter, and *tui* 兌 for the youngest daughter. The males of course are *yang,* and the females *yin.*

[7] *Shang-yang-tzŭ* says that True Spring is *tan.*

[8] None of the commentators known to us have a satisfactory explanation of the numbers.

the *lang chün* (husband) puts on mourning white.[9] If they are visible, then they cannot be used for our purpose. Things which are useful are invisible. They encounter one another in a state of obscurity whereby they make their changes indistinctly. At the moment when a flame flashes out suddenly, the *chên jên* 眞人 (true man) appears to us.[10]

Part II

Poems of Two Rhymes

Sixty-Four Poems to Imitate the Number Eight-Eight, hence the Sixty Four *Kua*

18. (1) It is advised first that *ch'ien* and *k'un* be procured as the *ting* and pot, and second that *wu* 烏 (crow) and *t'u* 兎 (rabbit) be put into them and treated in the same manner as in cooking. When you drive the two things into the *huang tao* 黃道 (yellow way), there is no reason why the *chin tan* will not form.[11]

19. (2) The arrangement of the *ting* (furnace) and the pot follows the method (or the will) of *ch'ien* and *k'un*. The compounding of the essences is capable of controlling the spirits. Changes occur through the gathering and scattering of the generative fluids of heaven and earth. I dare to say that this wonderful mystery is indispensable.

20. (3) Do not waste your time in building mud furnaces for *tan*. The compounding of medicines should be carried out in a *yen yüeh lu* 偃月爐 (lie-down-moon furnace)[12] which has a natural true fire and season, and does not require a supply of wood or charcoal and the blowing of air.

21. (4) The *yü jui* (jade bud) is produced in the *yen yüeh lu* (lie-down-moon furnace).[13] Quicksilver lies flat within the *ting* (furnace) of cinnabar. *Huang ya* (yellow sprout) grows gradually because of the force of the regulated fire.

22. (5) It is the practice of common people to take doses of saliva and *ch'i* (ethereal essence), but the medicine must be present before it can create anything. If the true seed or germ of the medicine is not found in the *ting* (furnace), the operation will be as futile as firing an empty kettle.

23. (6) In blending lead and mercury to produce *tan*, the amount of each should be such that it does no harm to the other. If you wish to inquire what the true lead is, the answer will be that the moonlight shines all day long on the western river. (Compare Title of Part III.)

24. (7) Do not go into the mountains before you succeed in compounding the *huan tan* 還丹 (returned medicine), for no sign of lead appears either on the exterior or in the interior of mountains. This kind of precious thing will be found in every house. Nevertheless, ignorant people are not able to recognize it.

25. (8) For repairing a broken piece of bamboo ware, you must use bamboo. When you want your hen to hatch chickens, eggs and not stones must be supplied. Working on medicines of unlike kinds is merely a waste of energy. What can be better than the true lead for fulfilling the secrets of the sages?

26. (9) In the use of lead it is not allowable to employ the vulgar lead. The true lead after its use is nonetheless discarded. This is the rule of using lead. It is a sure statement that lead is used and is not used up.

27. (10) The terms, empty mind and full stomach, contain deep meanings. It is possible for an empty mind to accept readily the warm feelings (of those who show the way). But it is even better first to compound the lead (medicine) to fill the stomach—by which means the hall dazzling with gold and jade can be attained.

28. (11) I dreamed that I visited *Hsi-hua* 西華 (West Beauty) and also arrived at *Chiu-t'ien* 九天 (Ninth Heaven),[14] and there I met the *chên jên*, the *hsien*, by whom I was given the essay,

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[9] *Hsieh Tao-kuang* says that *nü tzŭ* is the *ch'i* (ethereal essence) of the Dragon, *lang chün* that of the Tiger, and that *chên jên* is *chin tan*.

[10] This is an extra poem beyond the sixteen which the author mentions in his sub-title. It is a poem in two rhymes—and symbolizes the grand One which contains the true *ch'i*.

[11] *Hsieh Tao-kuang* says that *ch'ien* and *k'un* stand for the Sun and the Moon, that *huang tao* is the favored central position at which *chin tan* is formed, and that *wu* and *t'u* are again the *ch'i* (ethereal essences). *Ch'ien* and *k'un* are commonly known to stand also for the heaven and the earth.

[12] *Wei Po-yang* in the *Ts'an t'ung ch'i* says: "Like the moon lying on its back is the shape of the furnace and the pot." *Isis*, *18*, 239 (1932).

[13] According to *Hsieh Tao-kuang*, *yü jui* is *yang* substance or the *ch'i* (ethereal essence) of the Dragon, and Quicksilver is *yin* substance or the *ch'i* of the Tiger.

[14] These two places are popularly known as desirable parts of heaven.

Chih hsüan p'ien 指玄篇 (Guide to the Mystery).[15] There is not much mentioned in the essay, and everything in it is simple and easy. Its main idea is to teach the people how to compound mercury and lead.

29. (12) *Tao* resides in the domain of emptiness, and produces a single *ch'i*. From this *ch'i* the forces of *yin* and *yang* are born. Through the combination of *yin* and *yang* the three bodies[16] are formed. Having these three material bodies, we get all things in the universe.

30. (13) Thunder roars in *chin* (metal) and *shui* (water). Fire blazes with *yin* and *yang* in the *K'un-lun* 崑崙 mountains (the range of Koulkun mountains in Gobi and Tibet). If the two things agree with each other, the *tan* will ripen naturally and will perfume the person (who works with it) with a fragrance throughout his body.

31. (14) If the *kua* of *li* and *k'an*[17] return without *wu ssŭ* (matchmaker, go-between), though the four signs are present,[18] the *tan* will not form. It is because both *li* and *k'an* contain the true earth that the return of *chin tan* is made possible.

32. (15) The sun placed in the *li* position becomes female, and the moon placed in the *k'an* position becomes male. One who cannot understand this principle of topsy-turvy-ness should not talk about his knowledge of these matters, for that knowledge is only as broad as vision through a tube.

33. (16) If we put the solid heart of *k'an* upon the hollow center of *li*, we get a coincidence of the inside and the outside, and the *kua* of *ch'ien* (☰) is formed which represents a perfectly strong body and which can hide or fly away at will.[19]

34. (17) The Dragon is a *yang* substance but comes from the place of *li*. The Tiger belongs to *yin* but is produced in the place of *k'an*. The two things are able to reverse the ordinary process in such fashion that a mother is born to her daughter. The five elements should enter wholly into the central position.

35. (18) When the half moon hangs high in the sky (the time *yang* begins to grow), one can hear the shouting of the Dragon and the roaring of the Tiger. Then he should start his work of treating two-eights (compounding in the right proportion). At this particular favored time, the *tan* will form within an hour.[20]

36. (19) The male Tiger roars on the western mountains of *Hua* 華; the female Dragon howls under the deep eastern sea of *Fu-sang* 扶桑. *Huang p'o* 黃婆 (yellow dame) (the matchmaker) knows how to bring them together and how to enable them to marry with unchanging loving hearts.

37. (20) The white Tiger grows angry in the western mountains and the green Dragon is irresistibly fierce in the eastern sea. Capture them with both hands and let them fight to death. They then change into a layer of the powder of purple gold.

38. (21) The red Dragon and the black Tiger are situated one in the east and the other in the west. The four signs 四象 interlock each other at the position of *wu ssŭ*. If, from this time onward, one can make use of the advantages of the *kua* of *fu* 復 (return) (*yang* begins to grow) and the *kua* of *kou* 姤 (meet) (*yin* begins to grow), who then says that *chin tan* will fail to form?

39. (22) It is suggested that one should first observe nature in order to understand what the five bandits[21] are and that he should then examine the ground in order to promote goodness for the

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[15] The commentator, *Tai Ch'i-tsung* says that the *Chih hsüan p'ien* was written in beautiful language, and discussed mercury and lead, but has probably been lost. In his commentary in our *Ming* edition he includes a song, two pages long, by *Kao Hsiang-hsien* 高象先, which is supposed to be similar to the *Chih hsüan p'ien*. A translation of this poem is soon to be published in *Isis*.

[16] The three bodies are commonly considered to be the sky, the earth, and mankind.

[17] The *li kua* is *yin;* the *k'an kua* is *yang*.

[18] *Shang-yang-tzŭ* says that the four signs are heaven, earth, sun, and moon.

[19] The *k'an kua* (☵) has a solid heart whereas *li* (☲) has a hollow center. *K'an* is *yang* and *li* is *yin*. *Hsieh Tao-kuang* says that *li* (☲) consists of *yang* on the outside and of *yin* on the inside, *k'an* (☵) of *yin* on the outside and of *yang* on the inside. If the inside *yang* is used to modify the inside *yin*, the result is *ch'ien*, a strong substance representing *tan*, whence the name *yang tan*.

[20] The commentator, *Wêng Pao-kuang* says that this time, being the clearest hour at which no material thing but *ch'i* is present, occurs only on a certain day of the year, at a certain hour of that day, in a certain quarter of that hour.

[21] According to *Shang-yang-tzŭ*, eyes, ears, nose, tongue, and passion are the five bandits of heredity; women, music, perfume, taste, and the sense of touch are the five bandits of the surroundings; and love, lust, greed, anger, and stupidity are the five bandits of the interior of the body. All of them consume the ethereal essence or energy of the body and thus prevent one from acquiring the *Tao*.

people. When the country becomes rich and the people live in comfort, they should be forced to fight. After they have fought, they will be able to arrive at the place where the sages live.

40. (23) When legions are commanded in battle, they should be divided into right and left wings. If the enemy occupies a position much more advantageous than your own, then you should advance only with the greatest care and caution fearing lest you may lose the priceless treasure of your family.[22]

41. (24) Fire is produced from wood the inflammability of which however is hidden (in its ordinary state). If you do not know how to grind it up and drill into it, you should not handle it clumsily.[23] Any accident which may result will probably be injurious to you. To overcome this difficulty, it is advised to seek for *chin kung* (golden fellow).[24]

42. (25) *Chin kung* was originally the son of our east neighbor, but he has been given to our west neighbor at whose house he is growing up and at whose table he eats. If anyone recognize him, let that man call him back and raise him in his home and then marry him to *ch'a nü* (elegant lady), the beloved bride.[25]

43. (26) *Ch'a nü* travels in known directions. The first of her trips is short, whereas the later trip is long. When she returns however, she enters the house of *huang p'o* (the matchmaker) and weds *chin-kung* as her aged husband.

44. (27) Even though you know what the red cinnabar and what the black lead are, your efforts will still be in vain if you do not understand the fire and the season.[26] Success generally depends wholly upon the degree of your learning or training, but a slight variation (of the fire?) will cause the disappearance of *tan*.

45. (28) The subject has been discussed truly in the *Ts'an t'ung ch'i* and in other books and songs. Nevertheless the fire and the season are never given in the written books. If one wishes to know the word-of-mouth rule which leads people to *hsüan* (mysterious), he should talk thoroughly about it with the *hsien*.

46. (29) The moon shines brightly on the eve of the fifteenth day of the eighth month. This is the time at which the gold essence appears plentifully. At the moment when a single *yang* rises, start your fire without delay.

47. (30) *Tan* is compounded at the moment when the single *yang* begins to appear. The lead and the *ting* (furnace) will become hot, and the light emitted by them will shine on the curtains and the shades. They receive the *ch'i* easily under these conditions. Care must be taken to avoid danger on the addition or the removal of substances.

48. (31) The mysterious pearl increases as *yang* increases. With the supreme domination of *yang*, *yin* is made to vanish gradually. After ten months of work, when the weather turns cold, the *tan* is then ripened. At this time the ghosts and spirits will also be threatened.

49. (32) At the time after the first half-moon and before the second half-moon, the taste of the medicines is insipid and all of the appearances are shown. The medicines should then be collected and compounded in the furnace in which tonic products for your own cooking will be obtained.

50. (33) The first son suddenly drinks the wine of the west, and the young lady is in the north garden where flowers are growing for the first time. If *ch'ing ê* 青娥 (green woman) is led to meet them, they will be locked in *Huang*'s house (*huang p'o*) at that time.

51. (34) The months of *t'u* 兔 (rabbit) and *chi* 雞 (cock) are the most particular times.[27] The medicines which arrive at one's door seem to be penalty on the one hand and beneficence on the other.[28] At these times the man who is working on gold and cinnabar should stop his work, and wash his hair and his body. If fire is still applied, danger will certainly follow.

52. (35) The sun and the moon meet each

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[22] *Hsieh Tao-kuang* says that this verse is a metaphor for the application of fire. The same commentator says in another place that *tan* is formed in consequence of a battle between the Tiger and the Dragon.

[23] *Shang-yang-tzŭ* says that wood symbolizes the person himself, fire the ethereal essence, inflammability love and lust, and grind up and drill into symbolize study and investigation.

[24] *Chin kung*, according to *Hsieh Tao-kuang*, is the true lead.

[25] *Ch'a nü* is mercury according to *Hsieh Tao-kuang*.

[26] *Hsieh Tao-kuang* says that sages tells us only the materials, but the fire, which is known only by the *hsien*, is never told.

[27] The commentator, *Tzŭ-yeh* says that these months (respectively February and August) are the times in which spring and autumn are not clearly defined, so that the season is made up of *yin* with internal *yang* and of *yang* with internal *yin*: therefore the fire should be stopped.

[28] According to *Hsieh Tao-kuang*, *t'u* represents beneficence and *chi* penalty.

other once in a period of thirty days. By imitating the divine efficacy one can accomplish the work of a day in a single hour. It is possible to forecast whether the defense of the city and the offense in the field are lucky or unlucky.[29] The formation of the efficacious cinnabar makes the *ting* fully red.

53. (36) By the interlocking of the *kua* of *p'i* 否 and *t'ai* 泰 everything in the universe is formed. The *kua* of *t'un* 屯 and *mêng* 蒙 constitute the starting point of creation.[30] For understanding the delightful principle here, it is unnecessary to bring out the *hsiang*. Otherwise, you will find that the series of *yao* 爻 is laborious to investigate.[31]

54. (37) *Hsiang* are invented to put under the *kua* and are merely forms (for explanation). After you grasp the idea from them, they may be forgotten. Unfortunately, unintelligent workers of succeeding generations are bigoted on the *hsiang* and hope to rise and fly by practicing the *kua* and *ch'i*.

55. (38) Heaven and earth become *ying* 盈 (full, generating) and *hsü* 虛 (weak, degenerating) at definite times.[32] By examining this rule, one may get its key. From the beginning to the end, it has long been stated that the *Tao* will be acquired when all of the three corpses are destroyed.

56. (39) If you wish to be a god of the mountain and live forever, you must build a foundation on *hsüan* 玄 (mystery) and *p'in* 牝 (female animal). When the true essence goes back to the golden cabinet, a single spot of divine light forms and will never tarnish.

57. (40) The doors of *hsüan* and *p'in* are seldom known by the people. They are really not the nose and the mouth, as some persons think. Even if you practice breathing for years,[33] how can you make the golden *wu* (crow) capture the *t'u* (rabbit)?

58. (41) Having different names but coming from the same origin,[34] the two things are not usually recognized by people. Both of them, being mysteries of mysteries, become important keys. A man should be able to distinguish the injurious substances from the beneficial. For preserving life and taking care of the form, the Purple *Chin tan* is the most wonderfully strange.

59. (42) When a man begins with *yu tso* 有作 (acting, performing), the process is hardly recognizable. When he ends with *wu wei* 無爲 (not-doing, remaining passive), the people then realize it. *Wu wei* is known as the greatest of wonders. However *yu tso* serves as the foundation.[35]

60. (43) White within black is the mother of *tan*. Female within male is the sage womb.[36] The grand One[37] should be watched carefully when in the furnace. Then the gathered valuables of the three lands will satisfy the three terraces (temples in heaven).

61. (44) Hunt for the having-picture in the indistinguishable land, and search for the true essence in the obscure world. Real and unreal now blend into each other.[38] Yet I do not know

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[29] According to *Hsieh Tao-kuang*, divine efficacy means skill in firing, and offense in the field means the union of Tiger and Dragon.

[30] According to *Wêng Pao-kuang*, *p'i* (䷋) and *t'ai* (䷊) are two of a series of compound *kua*, and stand for half *yin* and half *yang*, not hot and not cold, and *t'un* and *mêng* (compound *kua*) are the heads of all *kua* and stand for the starting of the fire or the starting point of receiving creation.

[31] The terms *yao* and *hsiang* both mean the lines which compose the *kua*. When the lines signify motion or change they are called *yao;* when they signify pictures they are called *hsiang*. Continuous *yao* are *yang;* broken *yao* are *yin*.

[32] *Shang-yang-tzŭ* says that when the tide rises it is *ying* (full, generating), and when it ebbs it is *hsü* (weak, degenerating). These are the *ying-hsü* of heaven and earth. A full moon is *ying* and a waning moon is *hsü*. These are the *ying-hsü* of the moon. Things germinate in spring, grow in summer, degenerate in autumn and are exterminated in winter. These are the *ying-hsü* of the four seasons. When a man's *ch'i* is strong it is *ying*, when weak it is *hsü*. These are the *ying-hsü* of the human body. At the hour of *kuei shêng* (belong-to-growth) lead is formed, and at the hour of *wang yüan* (after the full moon) lead is worthless. These are the *ying-hsü* of *chin tan* (gold medicine).

[33] Deep breathing as a means of attaining longevity and immortality.

[34] *Tzŭ-yeh* says that the single *ch'i* is divided into *yin* and *yang*, and thus has two different names; but both of these are produced by *T'ai chi* 太極 (the primordial) and have the same origin.

[35] According to several commentators, the compounding of *tan*, known as *yu tso*, by working with substances which have material form, is the early stage, while the ascent as *hsien* without material form, *wu wei*, is the later one.

[36] *Shang-yang-tzŭ* says that white within black is the *yang* which is present in *yin*. Female within male is the *yin* which is present in *yang*.

[37] I. e. the true single *ch'i*, according to *Wêng Pao-kuang*.

[38] *Hsieh Tao-kuang* says that having-picture is the *ch'i* of the Dragon; true essence is the *ch'i* of the Tiger; real and unreal are the *ch'i* of lead and mercury. Be-

how (the *chin tan*) can be obtained merely by thinking.

62. (45) When the four signs gather together, the mysterious body appears. A purple light shines where the five elements are perfected. Coming out from the womb and entering into the mouth, it (the mysterious body) enables a man to penetrate to the land of the sages. Then he will see the striving of countless dragon-gods.

63. (46) When he has finished the banquet at *Hua-ch'ih* (Beautiful Pond) where the moon shines brightly, he (the accomplished) rides on a golden dragon to visit *Tzŭ-wei* (the star gods). From that time onward, when all of the *hsien* have been interviewed, he rides above wide mountains and wherever he likes.[39]

64. (47) Whoever wishes to know the method of compounding *chin i huan tan* (gold fluid returned medicine) ought to begin by seeding and planting it in his own garden. It is needless to borrow the help of blowing or fanning (the fire): the *tan* will ripen naturally and emerge from the true womb.

65. (48) Do not consume your energy in practicing wrong and not-genuine methods, or adopt no-death instructions from other schools. The wine of continuing-life is added to the pot from time to time, and from the *ting* you will receive the liquor of returning-soul.

66. (49) Snow-mountain produces *t'i hu* 醍醐 (a reddish spirit) which will be poured into the creating furnace of Eastern *yang*.[40] When *Chang-ch'ien* 張騫 succeeds in passing over the mountains of *K'un-lun*, he is then able to see *Ma-ku* 麻姑.[41]

67. (50) If a man does not understand *yin* and *yang*, or host and guest, he will not be able to recognize whether their relations are close or not. Those who try to make use of their wives' essence will close the door to success. I do not know how many persons have failed in this way.[42]

68. (51) There are numerous living things each of which will return to the place from which it came. Returning-to-origin and fulfilling heaven's will mean imperishable. The people usually do not understand the process of realization-of-constancy and back-to-the-initial-form, and often procure unfortunate results by practicing wrong methods.

69. (52) *Ou Yeh* 歐冶 (a sword smith) gave oral instruction to his disciples in the method of making swords. The spiritual sword *Mo Yeh* 鏌鋣 (produced by them) derives its unconquerable power from the control and proportioning of the elements of *chin* (gold) and *shui* (water). After it was made, it knew the will of the person (who wore it) and killed devils at distances of thousands of miles with the lightning's speed and with the lightning's glare.[43]

70. (53) By drumming on a bamboo pipe, summon the tortoise to swallow the *yü chih* 玉芝 (plant of long life). By thrumming on a lute, call down the phoenix to drink the *tao kuei* 刀圭 (a small scepter?).[44] Forthwith a golden light appears throughout the body (of the compounder), and he will not discuss his art any more with the common people.

71. (54) The medicines when put together must be of the same sort in order to form a picture. *Tao*, when in the sense of *hsi i* 希夷 (unusually easy of access), will coincide with the doctrine of nature. After a single grain of the efficacious *tan* has been taken into the stomach, a man will then know that his life is not controlled by heaven.

72. (55) The glorious *chin tan* can be prepared and finished in any convenient day. The instruc-

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cause of the stimulation of the real, the unreal gives a picture; the real, being stimulated by the unreal, become effective.

[39] *Tzŭ-yeh* says that *Hua-ch'ih* is the place where the medicines are produced, and that the finished banquet is the collection of a sufficient quantity of them.

[40] According to *Hsieh Tao-kuang*, snow-mountain means white color giving a picture of *chin*, hence it means also *chin tan* the taste of which recalls that of *t'i hu* spirit, a reddish liquor.

[41] *Chang-ch'ien*, according to *Hsieh Tao-kuang*, is a man-*hsien* representing *yang*, and *Ma-ku* a woman-*hsien* representing *yin*. Their meeting means the union of *yin* and *yang*. At the peak of *K'un-lun* there is supposed to be a door which admits to *hsüan* (mystery).

[42] *Hsieh Tao-kuang* says that certain persons have tried to make use of their wives' essence for compounding *yin* for attaining long life, and that this is like extinguishing fire by putting more wood on it.

[43] *Shang-yang-tzŭ* says that the sword was made neither from vulgar gold nor from vulgar iron, but that it was a spiritual sword comprising the foundation of heaven and earth and the backbone of *yin* and *yang*. *Hsieh Tao-kuang* says that this stanza is a metaphor for compounding *tan*.

[44] *Tzŭ-yeh* says that *yü chih* and *tao kuei* are names of medicines, and that the drumming on the bamboo pipe and the thrumming on the lute are the harmonious music of the mutual attraction of *yin* and *yang*. *Hsieh Tao-kuang* says that the tortoise is the black Tiger and the phoenix the pink Dragon.

tions of the ancient *hsien* should be followed. If anyone says that the compounding takes three years or nine years, his intent is only to make excuses and to stretch out the time.

73. (56) The learning of the great medicine is sometimes easy and sometimes difficult. It depends partly on us and partly on the will of heaven. If one does not perform good works and spread virtue in the *yin* district, his work will be handicapped frequently by groups of devils.

74. (57) It is the time that the three bodies (heaven, earth and men) steal from each other. *Tao tê* (Way of Virtue) is the secret key to becoming *shên hsien* 神仙 (immortal). A multitude of changes ends in tranquility, and all solicitude now ceases. The rationalization of one's body proves *wu wei* (not-doing).

75. (58) The Book of *Yin fu* (Amulets for *yin*) contains a little more than three hundred words, but the Book of *Tao tê* uses just five thousand for its marvelous exposition. From ancient times down to the present there have been countless *hsien* of above who all have acquired the truth from these same sources.

76. (59) Even if your intelligence is above that of *Yen-tzŭ* 顏子 and *Min-tzŭ* 閔子 (two of the most clever pupils of Confucius), yet, merely with constrained conjecture, you will not be able to succeed (in *tan*) unless you have a true teacher. For the work of *chin tan* in case oral instructions are lacking, where and how can you fertilize the fecund womb?

77. (60) To begin with, a man should have a trained clear mind. The three thousand merits (of the medicine) will enable him to live as heaven does. The *ting* will arrive naturally for the cooking of the Tiger and Dragon.[45] The compounder should not devote too much time to his family or be too strongly attracted to his wife and sons.

78. (61) Anyone who has not yet compounded the *huan tan* (returned Medicine) should work promptly at compounding it. As soon as he has succeeded, he ought to be contented. If he has a never-satisfied desire, he will some morning acquire unavoidable misfortune and disgrace.

79. (62) Regard the dead gate as the living gate. Do not take the living door for the dead door. Whenever a man understands the nature of death and comprehends the principle of topsy-turvy-ness, he sees that misfortune may result in kindness.

80. (63) Misfortune and happiness are each dominated by the other. They seem moreover to pursue one another through their influences. If a man can change the nature of life and death, misfortune will be changed into happiness as easily and as quickly as the turning of a hand.[46]

81. (64) Learning and conduct should be mingled with common things and united with light. Behold! a circle is a circle and a square is a square. No one foresees brightness and dusk, distress and equanimity. How can a man determine his going or stopping?

PART III

TWELVE IRREGULAR POEMS IN THE WEST-RIVER-MOON FORM SYMBOLIZING THE TWELVE MONTHS

West means the direction where the *chin* element
is found. River means the element water.
Moon means the utility of *tan*.[47]

82. (1) The internal medicine resembles closely the external medicine. Communication with the inside is just as indispensable as with the outside. The heads of the *tan* come into union, and reveal that they are of the same sort. The *wên* 溫 and *yang* 養 (tempering and tonic properties) which the medicines possess are the two actions.

(1a) There is the true natural fire within the furnace of which the glorious red lasts forever. The regulation of the external furnace should be done patiently. Nothing will surpass the supreme mystery of the true seed.[48]

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[45] *Wêng Pao-kuang* says that *Lü Tung-pin* 呂洞賓 (a *hsien*) has written a verse as follows: "There are three thousand hidden roads in *P'êng lai* (one of the three supernatural islands of the Eastern Sea, cf. *Ambix*, *1*, 109 (1937)). When a man walks through all of them, he will come back from the clouds step by step. Since the virtue for the *yin* district has been accumulated, a man will surely meet the *chên jên* (from whom he will receive instruction)." Therefore the statement here says that the *ting* functions naturally.

[46] *Hsieh Tao-kuang* says that *yang* controls life and is known as happiness. *Yin* controls death and is known as calamity. The decrease of *yin* increases *yang*, but *yin* grows at the extremity of *yang* and thus each dominates the other. This is known as the *Tao* of constancy.

[47] The name of the verse form means west-river-moon. There is one poem extra, thirteen altogether, the extra one symbolizing the extra month which occurs in certain Chinese years.

[48] *Hsieh Tao-kuang* says that when the *Tao* comes from within, the arrangement of furnace and *ting* are external; when *Tao* comes from without, *k'an* (a *kua*

83. (2) This very *Tao* is supremely wonderful and holy. What I fear is that your fate may be too scant for you to receive it. As early as the morning after the blending of mercury and lead,[49] you will see signs of the formation of the mysterious pearl.

(2a) If a determined scholar wants to learn *Tao*, he may live in a city or hold office at the same time without any inconvenience. The work is easy and the medicine is not far away. If the secret is disclosed, it will be so simple that every one may get a good laugh.

84. (3) The white Tiger is of the utmost value at the beginning. *Hua ch'ih* (beautiful Pond), *shên shui* (spiritual water) and *chên chin* 眞金 (true gold). We ought to be grateful for the profound kindness of heaven which gives us medicines which are not the vulgar materials.

(3a) If a man desires to compound the *tan* of the nine-changes, he must first build up *hsin* (heart). (The medicine) must be collected at a particular time, and distinction must be made between that which floats and that which sinks. Great care must be taken in the firing to prevent any danger.

85. (4) If you want the true lead to detain (fix) the mercury, in addition to their own affinities, the house-keeper[50] must be taken into account. Since wood and gold[51] are separate things from one another, they have no chance to meet unless a matchmaker lead them to it.

(4a) Wood possesses obedience and the property of loving gold. Gold is compassionate and also tends to attach itself to wood. Since happily they kiss each other, swallow each other and marry each other, it is found that the man is carrying a womb.

86. (5) To whose family does *ch'a nü* (elegant lady) of two-eight (age?) belong? Where is the *lang chün* (husband) of nine-three? They say that they are the fluid of wood and the essence of gold. When they come into contact with earth, they all change into a body of three.[52]

(5a) Again, they borrow the help of *ting kung* 丁公 (fellow-old-man) in compounding. Then the husband and the wife unite together with loving affinity. *Ho ch'ê* (river-car) dares not make the least delay and conveys them to the peak of the *K'un-lun* mountains.[53]

87. (6) The seven changes of red cinnabar restore the initial state. The nine returnings of the *chin i* 金液 (gold fluid) return to the truth. It is not necessary to count the hours, but success depends upon the adjustment of the *wu hsing* (five elements).

(6a) At the beginning, there is only a single dose of quick silver. When it flows through repeatedly, and sufficient *yin* and *yang* have been counted, it will naturally penetrate to God and go in and out without deserting *hsüan* (mysterious) and *p'in* (female).

88. (7) The female substance is held within the male. *Yin* embraces the essence of *yang*. The medicine will be produced by the harmonious action of the two and converts a man into a soul of a *hsien* or of a sage.

(7a) Believe (the miracles of) a grain of *chin tan* of *Tao*. When it is eaten by a snake, the snake is transformed into a dragon. If eaten by a cock, the cock changes into a roc or a phoenix and flies away into the clear region of True *yang*.

89. (8) The heaven and earth have been in the states of *p'i* and *t'ai*.[54] In the morning and the evening, we should pay attention to *t'un* and *mêng* (the heads of compound *kua*, hence starting substances). They are similar to the spokes of a wheel which converge into the hub, and similar to the waters (from many rivers) which pour down

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having *yang* properties) and *li* (a *kua* having *yin* properties), lead and mercury, have their place within. The external medicine is *chin tan* which is formed in a two-eight furnace. The internal medicine is the *chin i huan tan* which is compounded in the stomach. Then *tan* or *yang-tan* is used to stain or capture the *yin*-mercury of the body. *Shang-yang-tzŭ* says that the internal medicine relates to *hsing* (nature of men) whereas the external medicine controls both *hsing* and *ming* (will of God).

[49] *Tzŭ-yeh* says that *chin tan* consists merely of mercury and lead. Lead is found outside whereas mercury is obtained from within the body.

[50] *Hsieh Tao-kuang* says that the house-keeper symbolizes the true *ch'i* of the compounder.

[51] According to *Hsieh Tao-kuang*, gold symbolizes lead and is external, wood symbolizes mercury, and is internal. Therefore these two things are separate things.

[52] According to *Shang-yang-tzŭ*, *ch'a nü* is the mercury of *li* (a *kua*); *lang chün* is the lead of *k'an* (a *kua*). Earth causes them to unite into one thing. *Tzŭ-yeh* says that earth is the go-between.

[53] According to *Hsieh Tao-kuang*, two-eight is a *yin* number, *ch'a nü* is the true mercury of our body; three-nine is a *yang* number; and *lang chün* is *yang tan*. Earth is the pot and *ting kung* is fire. *Ho ch'ê* is water.

[54] Two of the compound *kua*, no good and good, chaotic and quiet, unhappy and happy, etc.

into the sea. The secret lies in removing, adding and utilizing.

(8a) Get one (grain of *tan*) and you will be sufficient for thousands (of affairs). Do not make distinction between south, north, west and east.[55] Fail and fail again; but build upon your previous achievements. The valuable things of life should not be toyed with.

90. (9) At the time of the winter solstice, a single *yang* appears with the returning of the *kua* of *fu*. After every three decades of days, another single *yang-yao* 陽爻 is added to it.[56] However, within the month, the *kua* of *fu* (return) (the *kua* of the winter solstice) comes to pass in the shortened cycle of the moon and tide.[57] At the end of the full moon and at the close of the *kua* of *ch'ien* (the month with six single *yang*), the sign of the growing of the *kua* of *kou* 姤 (meet) (the month with one single *yin*) may be seen.[58]

(9a) A day in its turn is divided into periods of winter and summer.[59] The single *yang* begins to grow up at midnight. At noon, a single *yin* comes with the representation of *kou* of the *hsiang* series. A man who prepares medicines ought to know morning and night.

91. (10) A man who fails to recognize the *wu hsing* (five elements)[60] and the four signs is certainly one who will be befuddled to differentiate cinnabar, mercury, lead, and silver. He has never even heard of the principle of the fire and the season for compounding *tan*, and he dares to say that he is a great devotee of Taoism.

(10a) Never considering his mistake, he teaches others in turn, and teaches mistakenly. He ruins the mercury of others by misleading them into an uncharted port. How can one have the heart to do this?

92. (11) The virtues must be built more than eight hundred times. The good works of the *yin* district must be performed as many as three thousand times. External objects and the self, enmity and love, should be treated as of equal importance. They will then fulfill the original will of the *shên hsien* (immortals).

(11a) Since (the body is) invulnerable to harm by tiger or by rhinoceros, by sword or by arms, and unburnable by unexpected fire, the priceless amulet, after it descends upon (the body), can go (with it) to heaven where it acts to protect the harness, the carriage, and the chariot (of its possessor).

93. (12) (The constellations of) the Weaver and the Herdboy love each other. Tortoises and snakes do the same according to the principle of

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[55] *Tzŭ-yeh* says that the efficacy of the medicine makes all things fuse into one and return to *T'ai chi* (primordial) and *T"ai chi* has no direction.

[56] A *yao* is a line of a *kua;* a *yang-yao* is an unbroken line, a *yin-yao* a broken one.

[57] According to *Hsieh Tao-kuang*, a single *yang* grows up at the winter solstice. Its *kua* is *fu*, ䷗ 復, which has a single *yang-yao*. After thirty days, another *yang-yao* increases. The *kua* then becomes *lin* 臨 (arrive), ䷒. Again, thirty days more, the *kua* changes into *t'ai* 泰 (peace, stable), ䷊, having three *yang-yao*. Again, thirty days more, *ta chuang* 大壯 (great-strong), ䷡, having four *yang-yao*, is the *kua*. The *kua* of *kuai* 夬 (pure name of the *kua*, no other meaning), ䷪, with five *yang-yao*, forms in the following thirty-day period. The *kua* of *ch'ien* 乾 or pure *ch'ien* (heaven), ䷀, with six *yang-yao* is known as full and is formed in April. After the extremity of *yang*, *yin* begins to grow. At the time of summer solstice, a single *yin* appears with the *kua* of *kou*, 姤 ䷫, (meet), with one *yin-yao* 陰爻. In the same manner with thirty days as the period, the successive *kua* are *tun* 遁 (retire), ䷠, with two *yin-yao; p'i* 否 (unstable), ䷋, with three *yin-yao; kuan* 觀 (view), ䷓, with four *yin-yao; po* 剝 (to tear-away), ䷖; and *k'un* 坤 (mother, earth), ䷁. After the full *yin*, *yang* grows up again and the cycle is repeated. This is known as the fire and season of the year.

[58] The sages are able to alter this system, according to the same commentator, by condensing the fire and time-cycle of a year into one month. The first day of the moon is taken as the *kua* of *fu*, ䷗; thence with appropriate *kua* until the fifteenth of the moon, when the *kua* of pure *yang*, ䷀, is assigned. So two and a half days here are equivalent to thirty days of the previous cycle. In the sixteenth of the moon, a single *yin* grows, therefore the text says that at the end of the full moon or at the close of *ch'ien*, the growth of *kou* (with a single *yin-yao*) may be seen.

[59] The sages again, according to *Hsieh Tao-kuang*, shorten the cycle by putting the month-cycle into a single day. The day is divided into four seasons, i. e., summer, winter, etc. A single *yang*, the *kua* of which is *fu*, ䷗, appears at midnight. By noontime, a single *yin*, the *kua* of which is *kou*, ䷫, grows up. This is known as the increasing and decreasing of *yin* and *yang*.

[60] *Shang-yang-tzŭ* says that lead, mercury, cinnabar, silver, and earth are the *wu hsing* (five elements) of *huan tan* (returned medicine) and that the *ch'ien*, *k'un*, *k'an*, and *li* (*kua*) are the four signs of creation.

nature.[61] The *shan* (toad) and the *wu* (crow),[62] at the time when there is no moon, unite together and enjoy (their) beauty. The two forces help one another and revolve around each other.

(12a) Originally, (the two forces) resulted from the skillful utilization of *ch'ien* and *k'un*. How many, however, are able to go so deeply into this bottomless gulf? The separation of *yin* and *yang* is a great fault; and how then can we make (our life) as long as heaven and as wide as the earth?

94. (13) *Tan* is the supremely priceless valuable medicine of the material body. Successful compounding leads to endless changes; it makes it possible for one to ascend to meet the *chên tsung* 眞宗 (true men) and further to solve the (problem) of *wu shêng* (non-living) by its skillful use.

(13a) There is no need to wait until another life or for future generations (in order to see the effect). Before you is the Buddha who proves to you the possibility of penetrating to God. Since *Lung nü* 龍女 (Dragon Lady),[63] has acquired success, who afterwards can advance farther?

Part IV

Five Poems of Two Rhymes Symbolizing the Five Elements of Lead, Mercury, Cinnabar, Silver, and Earth

95. (1) Even if you are able to apprehend the true nature of Buddhism (i. e., to become of a Buddha), you will not be able to avoid giving up your body here and acquiring another body there.[64] What can be better than compounding the great *tan* at the same time? Then you can overcome *wu lo* 無漏 (no leak) to become a *chên jên* (true man, *hsien*).[65]

96. (2) Rebirth, the taking of the place of the spirit of an embryo, a change of home and a return to a former residence, these are known as the four fluids. If one can make the Dragon surrender and the Tiger obey, how can the house which is built of true gold become ruinous?

97. (3) The mirroring of the form and the holding of the breath, these are (the ways of) realizing the wonderful *fa*. They are difficult for the beginner, but become a smooth road later. Even if you can travel through thousands of countries in a moment, why do you change your home back to your former residence?

98. (4) The Buddha teaches the people how to attain the supreme happiness, but the supreme happiness is situated in the direction of *chin*. Probably the material manifestations are actual facts. The other two are not true, and are not to be considered.

99. (5) Common speech often tells about the *Tao* of consenting sages. A man should search deeply into this matter. If he seeks in ordinary affairs according to the principle of topsy-turvyness, then the dust and the sand of the broad earth all become precious.

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[61] *Tzŭ-yeh* says that the Herdboy and Weaver belong to heaven. They meet once in a year by crossing the bridge formed by the magpies over the Silver River or milky way. Tortoises and snakes are bodies of the ground, yet they also manifest the two forces. The sun and the moon unite once in a month. All of these are mutual attractions of *yin* and *yang*.

[62] *Shang-yang-tzŭ* says that *shan* and *wu* are the moon and the sun.

[63] *Shang-yang-tzŭ* tells a short story of how *Lung nü* acquired *Tao*.

[64] Because a Buddha can not transform his body into non-material.

[65] According to *Tzŭ-yeh*, this suggests that a man should learn both *hsing* (nature of man, essential for becoming a Buddha) and *ming* (life, essential for becoming a *hsien*).

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Hsi-ning 熙寧 e, u, x.
Hsiang 象 5, 53, 54, 90.
Hsiang ch'uan 象川 w fn.
Hsieh Tao-kuang 薛道光 c fn., e fn., w, x, 11 fn., 17 fn., 18 fn., 21 fn., 33 fn., 40 fn,, 41 fn., 42 fn., 44 fn., 51 fn., 52 fn., 61 fn., 66 fn., 67 fn., 69 fn., 70 fn., 80 fn., 82 fn., 85 fn., 86 fn., 90 fn.
Hsien 仙 (immortal) b, c, p, r, s, u, af, 3, 15, 16, 28, 44 fn., 45, 59 fn., 63, 66 fn., 72, 75, 77 fn., 88, 95.
Hsin 心 y, z, ag, 84.
Hsing 性 (Nature of Man) g, y, z, ag, 82 fn., 95 fn.
Hsü 虛 55.
Hsü Chia-lin 徐家麟 k.
Hsüan 玄 (mysterious) 13, 45, 56, 57, 66 fn., 87.
Hsün 巽 (a kua) v, 11 fn.
Hua 華 (a mountain) 36.
Hua-ch'ih 華池 (Beautiful Pond) ac, 63, 84.
Huan tan 還丹 (Returned Medicine) 24, 78, 91 fn.
Huang Mien-chung 黃勉中 j.
Huang p'o 黃婆 (yellow dame, the matchmaker) 36, 43, 50.
Huang tao 黃道 (yellow way) 18.
Huang-ti 黃帝 ab.

Huang ya 黄芽 (Yellow Sprout) c, v, 6, 11, 21.
Hun yüan 混元 (Mixed Elements) e.
I mao 乙卯 x.
K'an 坎 (a kua) c, 4, 6, 11 fn., 31, 32, 33, 34, 82 fn., 86 fn., 91 fn.
Kan lu 甘露 (Sweet Dew) 6.
K'ang-hsi 康熙 k fn.
Kao Hsiang-hsien 高象先 28 fn.
Kên 艮 (a kua) v, 11 fn.
Kêng 庚 (a symbolic number) v.
Kou 姤 (a kua) 38, 90.
Ku chin t'u shu chi ch'êng 古今圖書集成 k fn.
Kua 卦 a, c, 4 fn., 5, 11, 31, 33, 38, 53, 54, 82 fn., 86 fn., 89, 90, 91 fn.
Kuai 夬 (a kua) 90 fn.
Kuan 觀 (a kua) 90 fn.
Kuang-hsü 光緒 k fn.
Kuei-lin 桂林 h.
Kuei shêng 癸生 7, 55 fn.
K'un 坤 (Earth) (a kua) c, 11 fn., 16, 18, 19, 90 fn., 91 fn., 93.
K'un-lun 崑崙 30, 66, 86.
Lang chün 郎君 (husband) c fn., 17, 86.
Lao-tzŭ 老子 ab.
Li 離 c, 4, 6, 11 fn., 31, 32, 33, 34, 82 fn., 86 fn., 91 fn.
Li Luan-hsüan 李鑾宣 k fn.
Lieh ch'uan 列傳 k fn.
Lieh hsien ch'üan chuan 列仙全傳 (Complete Biographies of the Immortals) d, m, q.
Lin 臨 (a kua) 90 fn.
Lin-hai 臨海 l, n, s.
Liu chu 流珠 (flowing pearl, mercury?) 7.
Liu Fêng-chên 劉奉眞 j.
Liu Hai-ch'an 劉海蟾 e, m, r.
Lu Shu 陸墅 x.
Lü tung-pin 呂洞賓 77 fn.
Lung nü 龍女 (Dragon Lady) 94.
Lung-t'u-lu-kung 龍圖陸公 h.
Ma Ku 麻姑 (a woman-hsien) 66.
Ma Mo Ch'u-hou 馬默處厚 h, r.
Mêng 蒙 (a kua) 53, 89.
Miao chiao 妙覺 (super-sense, wonderful awakening) ag.
Min-tzŭ 閔子 76.
Ming 明 (dynasty) u, x, aj, 28 fn.
Ming 命 (Life, Will of God) g, 82 fn., 95 fn.
Mo yeh 鏌鎁 69.
Nü tzŭ 女子 (lady) c fn., 17.
Ou Yeh 歐冶 69.
Pai hsüeh 白雪 (White Snow) c, 11.
Pai-pu-ch'i 百步溪 p, s.
Pai-pu-ling 百步嶺 p, r.
Pao-p'u-tzŭ 抱朴子 a fn.
Pên hsin 本心 y.
P'êng-lai 蓬萊 (a supernatural island for Hsien) o, 77 fn.
P'i 否 (a kua) 53, 89, 90 fn.
P'in 牝 56, 57, 87.
P'ing-shu 平叔 (Peaceful Younger) e, m, n, p, r, u, x, ah.
Po 剝 (a kua) 90 fn.
Po-tuan 伯端 p, s, u, ad, ae, af, ag.
Po wu hui p'ien 博物彙篇 k fn.
San ch'ing 三清 16.
Shan 蟾 (Toad) c, 93.
Shan-hsi t'ung chih 山西通志 (General Record of Shansi Province) k fn., q.
Shan-hsi t'ung chih 陝西通志 (General Record of Shensi Province) k fn., m.
Shang-yang-tzŭ 上陽子 c fn., x, 8 fn., 12 fn., 31 fn., 39 fn., 41 fn., 55 fn., 60 fn., 69 fn., 82 fn., 86 fn., 91 fn., 93 fn., 94 fn.
Shao-hsing 紹興 w fn.
Shê li 舍利 (Relics) i.
Shên i tien 神異典 k fn.
Shên hsien 神仙 k fn., 74, 92.
Shên shui 神水 (Spiritual Water) ac, 84.
Shui 水 (Water) c, 30, 69.
Shui chin 水金 (Watery Gold) 10.
Ssŭ-ch'uan 四川 e, r, u, ad.
Ssŭ-ch'uan t'ung chih 四川通志 k fn.
Ssŭ k'u ch'üan shu tsung mu ti yao 四庫全書總目提要 (Abstract of the Comprehensive Treatise on Books of the Four Cabinets) k fn., t.
Sung 宋 (dynasty) e, h, u, x.
Ta chuang 大壯 (a kua) 90 fn.
Ta-mo 達磨 (a Buddha) ag.
T'ai 泰 (a kua) 53, 89, 90 fn.
T'ai chi 太極 (the primordial) 58 fn., 89 fn.
Tai Ch'i-tsung 戴起宗 u, w, x, 28 fn.
T'ai-chou 台州 l, m, r.
T'ai-chou-fu 台州府 k fn., l.
T'ai-chou-fu chih 台州府志 (General Record of the District of T'ai-chou) k fn, r.
Tai-shang-wêng 太上翁 16.
Tan 丹 r, u, ad, ae, af, 6, 11 fn., 12 fn., 13, 15, 20, 23, 30, 31, 33 fn., 35, 40 fn., 44, 47, 48, 59 fn., 60, 64, 69 fn., 71, 76, 82, 84, 89, 91, 94, 95.
Tao 道 (Way) e, g, y, z, aa, ab, ad, ag, 1, 9, 10, 12, 15, 29, 55, 71, 80 fn., 82 fn., 83, 88, 94 fn., 99.
Tao kuei 刀圭 70.
Tao tê 道德 (Way of Virtue) ac, 74, 75.
T'i hu 醍醐 66.
T'ien-t'ai 天台 e, l, r, u, x.
Ting 鼎 (tripod, furnace) ae, 4, 18, 19, 21, 22, 47, 52, 65, 77, 82 fn.

Ting-hui 定慧 e.
Ting kung 丁公 (fellow-old-man) 86.
Ts'an t'ung ch'i 參同契 a, b, v, 20, 45.
T'u 兎 (rabbit) b, c, 18, 51, 57.
Tui 兌 (a kua) v, 11 fn.
Tun 遁 (a kua) 90 fn.
T'un 屯 (a kua) 53, 89.
T'ung-fu 同甫 w fn.
Tzŭ 子, k fn.
Tzŭ-wei 紫微 j, 63.
Tzŭ-yang 紫陽 (Purple Yang) c fn., e, f, g, j, m, p, r.
Tzŭ-yang-chên-jên 紫陽眞人 p, r.
Tzŭ-yeh 子野 x, 51 fn., 58 fn., 63 fn., 70 fn., 83 fn., 86 fn., 89 fn., 93 fn., 95 fn.
Wang-wu 王屋 j.
Wang Chou-yao 王舟瑤 k fn.
Wang yüan 望遠 7, 55 fn.
Wei Po-yang 魏伯陽 a, b, 20 fn.
Wei Yang-yü 維揚于 j.
Wên 溫 82.
Wêng Pao-kuang 翁葆光 u, w, x, 35 fn., 53 fn., 60 fn., 77 fn.
Wu 烏 (crow) b, c, 18, 57, 93.
Wu chên p'ien 悟眞篇 a, b, c, h, m, r, t, u, x, ad, af, ai, aj.
Wu hsing 五行 (Five Elements) 3, 87, 91.
Wu lo 無漏 95.
Wu Lu-ch'iang 吳魯強 a fn.
Wu-ming-tzŭ 無名子 w fn.
Wu shêng 無生 (non-living) y, 94.
Wu ssŭ 戊巳 (matchmaker, go-between) 3, 14, 31, 38.
Wu wei 無爲 (not-doing) y, ag, 59, 74.
Wu wu 戊午 ah.
Wu yin 戊寅 ah.
Yang 養 (tempering and tonic properties) 82.
Yang 陽 (the positive principle) b, c, g, 4 fn., 7, 8, 9, 11 fn., 12, 15, 21 fn., 29, 30, 31 fn., 33 fn., 34, 35, 38, 46, 47, 48, 51 fn., 53 fn., 58 fn., 60 fn., 66, 67, 69 fn., 70 fn., 80 fn., 82 fn., 86 fn., 87, 88, 90, 93.
Yang-chou 揚州 (Yangchow) f.
Yang tan 陽丹 c fn., 33 fn., 82 fn., 86 fn.,
Yang yao 陽爻 90.
Yao 爻 53.
Yüan-ming w fn.
Yen-tzŭ 顏子 76.
Yen yüeh lu 偃月爐 (lie-down-moon-furnace) 20, 21.
Yin 陰 (the negative principle) b, c, g, 4 fn., 7, 8, 9, 11, 12, 13, 15, 21 fn., 29, 30, 31 fn., 33 fn., 34, 38, 48, 51 fn., 53 fn., 58 fn., 60 fn., 66 fn., 67, 69 fn., 70 fn., 73, 75, 77 fn., 80 fn., 82 fn., 86 fn., 87, 88, 90, 92, 93.
Yin fu 陰符 (Amulets of Yin) ac, 75.
Yin-yao 陰爻 90 fn.
Ying 盈 55.
Ying êrh 嬰兒 (the Infant) 14.
Ying-hsü 盈虛 55 fn.
Ying-tsung 英宗 of two different dynasties h, x.
Yü chih 玉芝 (plant of long life) 70.
Yü ch'ih 玉池 (Jade Pond) 4.
Yü ch'ing chin ssŭ ch'ing hua pi wên chin pao nei lien tan chüeh 玉清金笥青華秘文金寶內鍊丹訣 (The Secret of Compounding Internal *tan* from the Secret Papers in the Golden Clear Jade Box of *Ch'ing hua*), ai.
Yü jui 玉蕊 (Jade Bud) c, 21.
Yu tso 有作 (acting, performing) 59.
Yüan-fêng 元豐 i, m, u, ah.
Yung-chêng, 正雍 k fn.

RECORDS OF MEETINGS

One Thousand Two Hundred and Fortieth Meeting

October 13, 1937—Stated Meeting

The Academy met at its House at 8.20 P. M.

The President in the Chair.

There were present fifty-six Fellows and eight guests.

The records of the meeting of May 12 were read and approved.

The Corresponding Secretary reported the receipt of letters accepting Fellowship from Kenneth Tompkins Bainbridge, John Tileston Edsall, Gustavus John Esselen, Clarence Henry Graham, Joseph Henry Keenan, Ernest Orlando Lawrence, Walter Walker Palmer, Alfred Sherwood Romer, Clyde Orval Ruggles, Henry Southworth Shaw, George Walter Stewart, Jabez Curry Street, Harry Rudolph Tosdal, Louis Leon Thurstone, Joseph Warren, Harald Malcolm Westergaard; and of a letter accepting Foreign Honorary Membership from Henri Piéron.

The President announced the deaths of nine Fellows:—George Perkins Clinton (Class II, Section 2), John Albert Cousens (Class III, Section 4), Charles Homer Haskins (Class IV, Section 2), Frederic Eugene Ives (Class I, Section 2), Frederic Brewster Loomis (Class II, Section 1), Ogden Livingston Mills (Class III, Section 2), Thomas Nelson Perkins (Class III, Section 4), Herbert Weir Smyth (Class IV, Section 3), Charles Franklin Thwing (Class III, Section 4); and of two Foreign Honorary Members:—Albert Heim (Class II, Section 1), Victor Laloux (Class IV, Section 4).

The Fellows elected in May were then presented to the Academy.

The President introduced Professor Harlow Shapley, Chairman of the Rumford Committee, who, after giving an account of the Rumford Premium and stating the grounds on which the present award was made, presented the Rumford Medals to Dr. William Weber Coblentz.

Dr. Coblentz delivered an address on "A Radiometric Method of Measuring Ultraviolet Solar Intensities in the Stratosphere," illustrated with lantern slides.

The following papers were read by title: "Rough Compressibilities of 14 Substances to 45,000 kg/cm^2," "The Resistances of 19 metals to 30,000 kg cm^2," "Polymorphic Transitions up to 50,000 kg/cm^2 on Several Organic Substances." by P. W. Bridgman.

The meeting was dissolved at 9.45 P. M.

One Thousand Two Hundred and Forty First Meeting

November 10, 1937—Stated Meeting

The Academy met at its House at 8.30 P.M.

The President in the Chair.

There were present forty-seven Fellows.

The records of the meeting of October 13, were read and approved.

The Corresponding Secretary reported the receipt of letters resigning Fellowship from George H. Blakeslee and Alfred V. Kidder.

The Corresponding Secretary reported grants from the Permanent Science Fund, as follows:

1. To Prof. Charles Chupp, Cornell University, $400, to aid in finishing a monograph of the fungous genus *Cercospora*.
2. To Dr. Willi M. Cohn, Research Lecturer, University of California, $150, to be used in printing—in the Astrophysical Journal—the results obtained on the polarization of the solar corona in the 1932 and 1934 eclipse expeditions.
3. To Prof. Ada R. Hall and Helen W. Kaan, Wellesley College, $59, to assist in an histological investigation of the development of thyroid glands in rat embryos.
4. To Prof. Robert S. Harris, Mass. Institute of Technology, $300, for the purchase of mother's milk, to be used in an investigation of (a) the chemistry of the casein; (b) the antirachitic properties.
5. To Dr. Francis R. Hunter, Rhode Island State College, $250, toward the purchase of a Barcroft-Warburg Micro-Respirometer, to be used in a comparative study of respiration and permeability.
6. To Prof. Walter Landauer, Storrs Agricultural Experiment Station, $150, for the purchase

of an analytical balance to be used in connection with a quantitative study of growth in lethal embryos of Creeper and Cornish Fowl.

7. To Dr. Clarence C. Little, Director, Roscoe B. Jackson Memorial Laboratory, $1,000, to be used to study the incidence of tumors and other growth abnormalities in a species cross in mice.

8. To Dr. Karl E. Mason, Vanderbilt University School of Medicine, $500, for technical assistance in the development and standardization of reliable methods for the routine assay of food substances for their vitamin E content.

9. To Prof. Arthur F. Scott, Reed College, $500, for the purchase of apparatus to be used in determinations of the atomic weights of beryllium and bismuth.

10. To Drs. Kurt G. Stern and Abraham White, Yale University School of Medicine, $400, to be used for the construction of equipment for the study of the homogeneity and certain physical properties of highly purified protein preparations and protein derivatives.

11. To Dr. John H. Welsh, Harvard University, $200, to enable him, during his sabbatical, to visit the laboratories of Prof. Koller at Kiel, and Prof. Hanström at Lund.

12. To Prof. William F. Windle, Northwestern University Medical School, $500, for employing the services of a trained laboratory assistant in a study of neurological factors in the development of foetal respiration, and other general problems of foetal behavior.

The President announced the death of Frank Morley, Fellow in Class I, Section 1, and of Lord Ernest Rutherford, Foreign Honorary Member in Class I, Section 2.

The President read a brief account of the history of the Academy.

The following communication was presented:

Mr. Hervey W. Shimer: "Man's Ancestral Home," illustrated with lantern slides.

The following papers were presented by title: "Melanophore Responses in the Young of *Mustelus Canis*." by George H. Parker; "Some Adaptive Responses of Taxonomy to a Changing Environment," by Charles T. Brues; "The Four Transverse Magnetic Effects in Copper and their Change with Temperature: New Measurements," by Edwin H. Hall.

The President spoke of the necessity for increasing the Publication Fund.

The meeting was dissolved at 9.55 P. M.

One Thousand Two Hundred and Forty Second Meeting

DECEMBER 8, 1937—STATED MEETING

The Academy met at its House at 8.25 P. M.

The President in the Chair.

There were present sixty Fellows and four guests.

The records of the meeting of November 10 were read and approved.

The President announced the death of Edward Leamington Nichols, Fellow in Class I, Section 2.

The following communication was presented:

Mr. W. Cameron Forbes: "American Policies in the Far East."

Two papers were read by title: "The Heat Capacity and Pressure Variation of the Enthalpy for Steam from 38° to 125° C. Part V. Steam Research Program," by Samuel C. Collins and Frederick G. Keyes; "An Experimental Study of the Absolute Temperature Scale. V. The Reproducibility of the Ice Point and the Triple-Point of Water. The Temperature of the Triple-Point of Water," by James A. Beattie, Tzu-Ching Huang, and Manson Benedict.

The meeting was dissolved at 10.20 P. M.

One Thousand Two Hundred and Forty Third Meeting

JANUARY 12, 1938—STATED MEETING

The Academy met at its House at 8.20 P. M.

The President in the Chair.

There were present thirty-nine Fellows and four guests.

The records of the meeting of December 8 were read and approved.

The Corresponding Secretary reported that $545 had been received from non-resident Fellows in response to the appeal for aid for the Publication Fund.

He also announced that the President had appointed Roger Bigelow Merriman to represent the Academy at the Inauguration of Rufus Carrollton Harris as President of the Tulane University, New Orleans.

The President announced the death of one Fellow: Wilberforce Eames (Class IV, Section 2);

and of three Foreign Honorary Members: George Albert Boulenger (Class II, Section 3), Frantz Dahl (Class III, Section 1), and George Henry Falkiner Nuttall (Class II, Section 3).

The following communication was presented:

Mr. Wallace W. Atwood: "The Physical History of the Rocky Mountain Region: a Study in Geomorphology," illustrated with lantern slides.

The meeting was dissolved at 9.40 P. M.

One Thousand Two Hundred and Forty Fourth Meeting

FEBRUARY 9, 1938—STATED MEETING

The Academy met at its House at 8.15 P. M.

The President in the Chair.

There were present forty-three Fellows and two guests.

The records of the meeting of January 12 were read and approved.

The President announced the death of three Fellows: Francis Russell Hart (Class III, Section 4), William Henry Pickering (Class I, Section 1), Harry Walter Tyler (Class I, Section 1); and one Foreign Honorary Member: Alfred Barton Rendle (Class II, Section 2).

The following communication was presented:

Mr. T. North Whitehead: "Unrest in Industry: a Study of Human Relations among Manual Laborers."

The meeting was dissolved at 10 P. M.

One Thousand Two Hundred and Forty Fifth Meeting

MARCH 9, 1938—STATED MEETING

The Academy met at its House at 8.25 P. M.

The President in the Chair.

There were present fifty-one Fellows and eight guests.

The records of the meeting of February 9 were read and approved.

The Corresponding Secretary read a letter from Mrs. Bowditch thanking the Academy for flowers sent at the time of the funeral of Mr. Ingersoll Bowditch, Treasurer of the Academy.

The President announced the death of five Fellows: George Weston Anderson (Class III, Section 1), Ingersoll Bowditch (Class III, Section 4), Chester Noyes Greenough (Class IV, Section 4), George Ellery Hale (Class I, Section 2), and John Osborne Sumner (Class IV, Section 2).

The Nominating Committee was appointed by the President as follows:

William C. Graustein, of Class I
Kirk Bryan, of Class II
Joseph H. Beale, of Class III
Edgar S. Brightman, of Class IV

Later, when it was found that Professor Graustein would be unable to serve, the President appointed Professor Tenney L. Davis in his place.

On the recommendation of the Council the following appropriations were made for the ensuing year:

From the income of the General Fund, $7,100, to be used as follows:

for General and Meeting expenses	$ 900
for Library expenses	2,100
for Books, Periodicals, and Binding	1,200
for House expenses	1,800
for Treasurer's expenses	1,000
for use at the discretion of the President	100

From the income of the Publication Funds, $2,299, to be used for publication.

From the income of the Rumford Fund, $2,600, to be used as follows:

for Research	$1,850
for use at the discretion of the Committee	750

From the income of the C. M. Warren Fund, $900, to be used at the discretion of the Committee.

The following communication was presented:

Mr. Edward L. Thorndike: "Great Abilities: their Causation, Discovery, and Utilization."

One paper was read by title: "The Lower Permian Insects of Kansas. Part 8," by F. M. Carpenter.

The meeting was dissolved at 10.20 P. M.

One Thousand Two Hundred and Forty Sixth Meeting

APRIL 13, 1938—STATED MEETING

The Academy met at its House at 8.25 P. M.

The President in the Chair.

This meeting having been designated as Ladies' Night, there were present about 300 Fellows and guests.

The records of the meeting of March 9 were read and approved.

The Corresponding Secretary *pro tem.*, Mr. E. S. Brightman, announced that the Council had made the following grants from the Permanent Science Fund:

1. To Professor Ernst C. Abbe, University of Minnesota, Minneapolis, $500, toward expenses of a phytogeographical expedition to the east coast of Hudson Bay, contingent upon an additional $2,000 being secured elsewhere.

2. To Professor C. E. Allen and Professor D. C. Cooper, University of Wisconsin, Madison, $600, for technical assistance in further histological and cytological studies of root nodules on legumes.

3. To Mr. Orlan M. Arnold, Rensselaer Polytechnic Institute, Troy, N. Y., $300, for materials in a study of design and construction of apparatus for precise measurement of electrical characteristics of proteins, enzymes, hormones and other organic substances.

4. To Dr. Charles T. Berry, Johns Hopkins University, Baltimore, Md., $247, toward the expenses of collecting fossil Ophiurans in a micropaleontological problem of stratigraphy.

5. To Professor William C. Boyd, Boston University School of Medicine, $600, for assistance in a study of blood groups in Egyptian mumified bone and muscle.

6. To Mr. Frank K. Edmondson, Indiana University, Bloomington, $500, toward the cost of a photometer for astronomical purposes, contingent upon the remaining cost being secured elsewhere.

7. To Professor Llewellyn T. Evans, Montana State University, Missoula, $180, for the purchase of animals and materials to continue a study of the effect of certain hormones upon reptiles.

8. To Professor Frank T. Gucker, Jr., Northwestern University, Evanston, Illinois, $650, for assistance in a study of heat capacities and heats of dilution of solutions of amino acids.

9. To Miss Margaret Harwood, Director, Maria Mitchell Observatory, Nantucket, Mass., $500, for assistance in computations on photographs of the Scutum star cloud.

10. To Professor Hans O. Haterius, College of Medicine, Ohio State University, Columbus, $200, for purchase of animals for study of anterior-hypophyseal activity and effects.

11. To Professor Rachel E. Hoffstadt, University of Washington, Seattle, $250, in further support of a study of the virus of infectious myxomatosis of rabbits and of related viruses.

12. To Professor Norton A. Kent, Boston University, $500, for assistance in further measurements of the wave lengths of molecular spectra of hydrogen isotopes.

13. To Professor Donald H. Menzel, Harvard College Observatory, $950, toward the cost of fabrication of an electric coronagraph of original design, for the study of the solar corona outside of total eclipse.

14. To Dr. John Rock, Free Hospital for Women, Brookline, Mass., and Dr. Austin H. Brues, Harvard Medical School, $1,000, for continuation of a study of the electrical disturbance associated with human ovulation, and attempt to recover, fertilize, and culture human ova.

15. To Mr. Felix Saunders, University of Chicago, $200, for materials to continue studies of the relation between configuration of carbohydrates and their utilization by bacteria.

16. To Professor Joseph H. Simons, Pennsylvania State College, $500, for technical assistance in continuing a study of the physical and chemical properties of the fluorocarbons.

17. To Dr. Irwin W. Sizer and Dr. Bernard S. Gould, Massachusetts Institute of Technology, Cambridge, $300, toward the cost of a Barcroft-Warburg apparatus in a further study of bacterial dehydrogenase.

18. To Professor Carl G. Vinson, University of Missouri, Columbia, $500, for special apparatus for use in further investigations of active crystalline virus fractions.

The President announced the death of three Fellows: John Bates Clark (Class III, Section 3), Leighton Parks (Class IV, Section 1), and Benjamin White (Class II, Section 4).

The President spoke briefly on the history of the Academy.

President Karl T. Compton made a few remarks on the significance of academies in general and of this Academy in particular, and then introduced the speaker of the evening, Dr. Serge Koussevitzky, who addressed the Academy on "Music and Poetry. The Art of Musical Interpretation—with a Few Remarks about American Orchestras."

Two papers were read by title: "Amphibians and Reptiles in Nevada," by Jean M. Linsdale, presented by Joseph Grinnell; "Eugenia in Borneo," by E. D. Merrill and L. M. Perry.

The meeting was dissolved at 9.30 P. M.

One Thousand Two Hundred and Forty Seventh Meeting

May 11, 1938—Annual Meeting

The Academy met at its House at 8.20 P. M.

The President in the Chair.

There were present fifty-one Fellows and two guests.

The records of the meeting of April 13 were read and approved.

The Corresponding Secretary announced that the Council had appointed the following committees for the ensuing year:

Permanent Science Fund Committee: J. W. M. Bunker, Chairman, G. R. Agassiz, G. P. Baxter, Vannevar Bush, E. M. East, Hudson Hoagland, S. B. Wolbach;

Francis Amory Fund Committee: R. I. Lee, Chairman, W. B. Cannon, David Cheever, Leigh Hoadley, E. E. Tyzzer, Soma Weiss;

Committee on Policy: G. R. Agassiz, Chairman, T. L. Davis, Harlow Shapley.

He also reported the receipt of a letter from the American Philosophical Society stating that it would be glad to acquire further items to add to its already large collection of the papers and correspondence of the late Elihu Thomson and asking that the members be so informed.

The Corresponding Secretary announced that the Academy had received invitations to send representatives to the following celebrations and had either arranged for delegates or in case that was not possible had sent appropriate greetings:

Centenary of the Societas Scientiarum Fennica, at Helsingfors, April 28–29; Dedication of the Franklin Institute, Philadelphia, May 19–21; Centenary of Greensboro College, North Carolina, May 20–21; Centenary of Emory and Henry College, Emory, Va., June 4–8; Semicentennial of American Mathematical Society, in New York City, September 6–9.

The President announced the death of two Foreign Honorary Members: Edmund Husserl (Class IV, Section 1), and Hermann Georg Jacobi (Class IV, Section 3).

The following report of the Council was presented:

REPORT OF THE COUNCIL

Since the last report of the Council there have been reported the deaths of twenty-three Fellows:—George Weston Anderson, Ingersoll Bowditch, John Bates Clark, George Perkins Clinton, John Albert Cousens, Wilberforce Eames, Chester Noyes Greenough, George Ellery Hale, Francis Russell Hart, Charles Homer Haskins, Frederic Eugene Ives, Frederic Brewster Loomis, Ogden Livingston Mills, Frank Morley, Edward Leamington Nichols, Leighton Parks, Thomas Nelson Perkins, William Henry Pickering, Herbert Weir Smyth, John Osborne Sumner, Charles Franklin Thwing, Harry Walter Tyler, Benjamin White; and nine Foreign Honorary Members:—George Albert Boulenger, Frantz Dahl, Albert Heim, Edmund Husserl, Hermann Georg Jacobi, Victor Laloux, George Henry Falkiner Nuttall, Alfred Barton Rendle, Ernest Rutherford, Baron Rutherford.

Sixteen Fellows and one Foreign Honorary Member were elected by the Council and announced to the Academy in May 1937.

The roll now includes 763 Fellows and 110 Foreign Honorary Members (not including those elected in May 1938).

The annual report of the Treasurer was read, of which the following is an abstract:

General Fund

Receipts

Income on hand April 1, 1937		$ 2,129.62
From Investments	$3,217.68	
From Assessments	4,050.00	
From Admissions	110.00	7,377.68
		$ 9,507.30

Expenditures

Expenses of Library	$2,256.00	
Books and Binding	1,728.23	
Treasurer's Expenses	893.69	
General Expenses	858.79	
House Expenses	2,200.09	
President's Expenses	67.50	
		$ 8,004.30
Income transferred to Principal		337.00
		$ 8,341.30

Rumford Fund

Receipts

From Investments	$ 3,080.00
Less overdraft 3/31/37	169.74
	$ 2,910.26

Expenditures

Purchase and Binding of Books	$ 250.71	
Research and Medals	1,821.76	
Transferred to Publication Fund	293.61	
		$ 2,366.08
Income transferred to Principal		143.00
		$ 2,509.08

Publication Funds

Receipts

Income on hand April 1, 1937		$ 1,256.50
Appleton Fund Investments	$1,074.75	
Centennial Fund Investments	1,611.75	
Rumford Fund	293.61	
Publication Sales, etc.	994.07	
Contributions	720.00	
Lake Fund Subscriptions	2,914.96	7,609.14
		$ 8,865.64

Expenditures

Publications—General	$3,383.33	
Publications—Lake	1,496.40	
		$ 4,879.73
Interest on Bonds bought		40.36
Income transferred to Principal		117.90
		$ 5,037.99

C. M. Warren Fund

Receipts

Income on hand April 1, 1937	$ 362.14
From Investments	977.40
	$ 1,339.54

Expenditures

Research	$ 1,001.50
Income transferred to Principal	47.30
	$ 1,048.80

Francis Amory Fund

Receipts

Income on hand April 1, 1937	$ 8,424.43
From Investments	2,368.00
	$10,792.43

Expenditures

Publishing Statement	$ 85.50

Permanent Science Fund

Receipts

Income on hand April 1, 1937	$ 966.43
From Trustees	6,460.07
	$ 7,426.50

Expenditures

Grants	$ 5,684.00
Expenses	17.50
	$ 5,701.50

The following reports were also presented:

Report of the Library Committee

During the year 88 volumes and 46 numbers of serials have been borrowed by 17 Fellows and 13 libraries, and more have been consulted at the Academy. All books taken out have been returned or satisfactorily accounted for.

The number of volumes on the shelves at the time of the last report was 45,202. During the year 378 volumes were added, chiefly by binding serials, making the number now 45,580. This includes 33 purchased from the General Fund, 23 from the Rumford, and 322 received by gift or exchange.

The following sums were placed at the disposal of the Librarian during the past year:

Balance from General Fund	$ 758.98
Balance from Rumford Fund	.71
Appropriation from General Fund	3,500.00
Appropriation from Rumford Fund	250.00
Transferred from Printing Biographical Notices account	113.48
	$ 4,623.17

The expenses charged to the library account during the financial year ending March 31, 1938, were:

Salaries	$ 2,251.00
Binding:	
General Fund	650.40
Rumford Fund	63.35
Purchase of Books and Periodicals:	
General Fund	1,077.83
Rumford Fund	187.36
Miscellaneous Library expenses	5.00
	$ 4,234.94

The unexpended balance of $388.23 will be carried over to next year in accordance with the usual custom.

Since the Rumford Committee has discontinued its annual appropriation for the purchase of books and periodicals and for binding, it has been necessary to cancel some of our subscriptions beginning with 1938. The following journals, therefore, which were seldom used and which may be found in one or more libraries in Boston and Cambridge, have been taken off our list:

Annales des ponts et chaussées
Astronomische Nachrichten
Berliner astronomisches Jahrbuch
Elektrotechnische Zeitschrift
Jahrbuch über die Fortschritte der Mathematik
Journal of morphology
Monatshefte für Physik und Matematik
Mycologia
Neues Jahrbuch für Mineralogie, Geologie und Paläontologie
Zeitschrift für physikalische Chemie
Zentralblatt für Mineralogie, Geologie und Paläontologie

Respectfully submitted,
Hervey W. Shimer, *Librarian*

May 11, 1938.

Report of the Rumford Committee

The Rumford Committee has held two meetings during the Academy year (April 1, 1937 to March 31, 1938) and has carried on business on several occasions by mail.

The Committee has made the following grants in aid of research in light and heat:

1937	Grant Number		
April	336	To Professor G. H. Dieke of The Johns Hopkins University, Baltimore, Maryland, for the purchase of spectroscopic equipment	$300
April	337	To Professor Norton A. Kent of Boston University in further aid of his spectroscopic researches	300
November	338	To Professor George R. Harrison of the Massachusetts Institute of Technology in further aid of his spectroscopic researches, and particularly for the purchase of salts of rare earths	400
1938			
January	339	To Professor Francis Bitter, Massachusetts Institute of Technology, for the construction of a crystal for his magnetic researches	400
January	340	To Dr. Richard Tousey of Tufts College in aid of his researches in reflections in the ultraviolet	100
January	341	To Professor E. A. Fath of Carleton College, Northfield, to support a cooperative research on a Cepheid variable	175
		TOTAL	$1,675

In April 1937 the Committee voted to approve the action of Professor Theodore Lyman of Harvard in transferring to Professor George R. Harrison of the Massachusetts Institute of Technology a spectrograph bought by Professor Lyman's colleague Dr. O'Bryan with Grant Number 296, as Dr. O'Bryan has now left the vicinity.

In May 1937 the Committee voted to underwrite one-half the cost, but not exceeding $300, of a paper by Professor P. W. Bridgman published in the Proceedings of the Academy.

Respectfully submitted,
Harlow Shapley, *Chairman*

May 11, 1938.

Report of the C. M. Warren Committee

The Committee had at its disposal during the fiscal year 1937–1938, a balance of $18.64, plus an appropriation of $898.70, making a total of $917.34, of which $700 was appropriated to aid scientific investigations. Balance, $217.34. During the year a grant of $300 made in 1936 was paid from money reserved for this purpose.

Since the last annual report grants have been made as follows:

Professor Walter C. Schumb, Massachusetts Institute of Technology, $300, to assist in the construction of apparatus to be used in carrying out a program of research in radioactivity.

Professor Hermann Schmid, Technische Hochschule, Vienna, $150, to continue his researches in the study of intermediate compounds formed in chemical reactions and a detailed examination of the diazotizing process.

Professor Avery A. Ashdown, Massachusetts Institute of Technology, $100, to be used to purchase rare chemicals to be utilized in the study of the preparation and optical properties of cyclobutane.

Professor M. A. Rosanoff, Duquesne University, $150, to continue his investigations on steric hindrance, with special reference to the rates of esterification of organic acids.

Reports have been received from Messrs. Schmidt, Kirk, Allen, Blatt, Scatchard, Huntress, Heidt.

The papers listed below, which have not been previously reported, describe the results of investigations aided by the Warren Fund. In each case there is an acknowledgment by the author of the assistance received.

A. H. Blatt and R. P. Barnes: "The Second Order Beckmann Rearrangement." J. Am. Chem. Soc., *56,* 1148 (1934); "The Action of Alkali on Certain Acylated Ketoximes. I. The Effect of Structure and Configuration." J. Am. Chem. Soc., *57,* 1330 (1935); "The Action of Alkali on Acylated Ketoximes. II. Steric Hindrance to Alkaline Hydrolysis." J. Am. Chem. Soc., *58,* 1900 (1936).

Burris Cunningham, Mary MacIntyre and Paul L. Kirk: "The Microscopy of the Amino Acids and Their Compounds. III. Copper Salts." Separatabdruck aus Mikrochemie, Band XXI (1936).

Hermann Schmid: "Über den Mechanismus der Diazotierung." Ber., *70,* 421 (1937).

Herman Schmid: "Über Katalytisch-Polare Stoffe." Zeitschrift für Elektrochemie, *43,* 626–629 (1937).

C. F. H. Allen, M. R. Gilbert, and D. M. Young: "The Structure of Dipyrroles." The Journal of Organic Chemistry, *2,* No. 3, July, 1937.

C. F. H. Allen, E. E. Massey and R. V. V. Nichols: "The Action of Alkaline Reagents on Diphenylbenzoylbutyrolactone." J. Am. Chem. Soc., *59,* 679 (1937).

C. F. H. Allen and W. L. Ball: "Gamma-Benzoylbutyronitrile" J. Am. Chem. Soc., *59,* 686 (1937).

C. F. H. Allen and H. Rudoff: "The 3, 4-Diphenylchlorocyclopentenones and Related Compounds." Canadian Journal of Research, Sec. B, *15,* August, 1937.

JAMES F. NORRIS, *Chairman.*

May 11, 1938.

REPORT OF THE COMMITTEE OF PUBLICATION

During the year 1937–38 the Committee of Publication has held one meeting, its business having been chiefly transacted by conferences and correspondence. Nine numbers of the Proceedings have been published this year (Vol. 72, nos. 2–10). Another Fascicle (VII) of Prof. and Mrs. Lake's "Dated Greek Minuscule Manuscripts" has appeared. The number of subscribers to this series continues to increase.

The quantity published in the various fields represents very closely the proportion existing in the manuscripts submitted.

The chairman was able to attend an instructive conference of costs and methods of publication called by the American Philosophical Society and held at Philadelphia.

It is indeed a pleasure for the Chairman to acknowledge the hearty cooperation received from the members of the committee and from the several authors.

GENERAL PUBLICATION FUND

Receipts	
Balance, April 1, 1937	$ 450.35
Appropriation 1937–38	2,240.00
Grants and Subsidies	793.61
Sales of Publications	494.07
Gifts	720.00
	$4,698.03
Expenditures	
Transferred to Lake Publication Fund	$ 600.00
Printing Proceedings	2,547.62
Other expenses, postage, etc.	235.71
Balance, April 1, 1938	1,314.70
	$4,698.03

LAKE PUBLICATION FUND

Receipts	
Balance, April 1, 1937	$ 412.46
Transferred from General Publication Fund	600.00
Subscriptions	2,283.44
Sales	22.80
Miscellaneous	8.72
	$3,327.42
Expenditures	
Plates	$1,425.41
Other expenses, postage, etc.	70.99
Balance, April 1, 1938	1,831.02
	$3,327.42

Respectfully submitted,
CHARLES H. BLAKE, *Chairman.*

May 11, 1938.

Report of the House Committee

The House Committee has had at its disposal funds amounting to $2,683.72, made up as follows:

Balance from previous year	$ 438.72
Appropriation for 1937–1938	2,000.00
Received for use of rooms	245.00
	$2,683.72

Of this amount the sum of $2,230.24 has been spent for the routine expenses, janitor, light, power, heat, telephone, etc., and $214.85 has been spent for upkeep and equipment, making a total expenditure of $2,445.09, and leaving an unexpended balance of $238.63. Of this balance $123.40 has been transferred to other accounts, leaving $115.23 to be carried over to next year.

Meetings have been held as follows:

The Academy	8
American Chemical Society, Northeastern Section	8
Archaeological Institute of America, Boston Society	1
Boston Surgical Society	1
Friends of China, Inc.	4
Geological Society of Boston	1
New England Botanical Club	9
Special Libraries Association	1
Thursday Evening Club	1
	34

The Council Chamber has been used for the Academy Council and Committee meetings, and also by the Trustees of the Children's Museum, the New England Farm and Garden Association, etc.

A detailed list of expenditures follows:

Janitor	$ 974.00
Electricity: Power	56.16
Light	190.97
Fuel	587.95
Elevator	128.76
Gas	51.00
Telephone	108.36
Water	68.08
Ash tickets	9.90
Upkeep	178.95
Furnishings and equipment	35.90
Janitor's supplies and sundries	55.06
	$2,445.09

Respectfully submitted,
J. C. Hunsaker, *Chairman.*

May 11, 1938.

On the recommendation of the Assistant Treasurer, it was *Voted,* that the annual assessment for the ensuing year be ten dollars.

The annual election resulted in the choice of the following officers and committees:

Dugald Caleb Jackson, *President*
James Flack Norris, *Vice-President for Class I*
Walter Bradford Cannon, *Vice-President for Class II*
George Grafton Wilson, *Vice-President for Class III*
Arthur Stanley Pease, *Vice-President for Class IV*
Leigh Hoadley, *Corresponding Secretary*
Hudson Hoagland, *Recording Secretary*
Horace Sayford Ford, *Treasurer*
Hervey Woodburn Shimer, *Librarian*
Charles Henry Blake, *Editor*

Councillors for Four Years:

George R. Agassiz, of Class I
Donald H. McLaughlin, of Class II
Edmund M. Morgan, of Class III
Michael J. Ahern, of Class IV

Councillor for Two Years:

Henry S. Dennison, of Class III

Finance Committee:

Thomas Barbour
Paul J. Sachs
Alfred L. Ripley
Vannevar Bush

Rumford Committee:

Percy W. Bridgman
Harry M. Goodwin
Harlow Shapley
Charles L. Norton
Norton A. Kent
George W. Pierce
George R. Harrison

C. M. Warren Committee:

Gregory P. Baxter
Walter L. Jennings
James F. Norris
Tenney L. Davis
Frederick G. Keyes
Reid Hunt
Charles A. Kraus

Committee of Publication:

Charles H. Blake, *Chairman*
Edwin C. Kemble, of Class I
Frederic T. Lewis, of Class II
Joseph H. Beale, of Class III
Robert P. Blake, of Class IV

Committee on the Library:

Hervey W. Shimer, *Chairman*
Raymond C. Archibald, of Class I
Thomas Barbour, of Class II
Nathan Isaacs, of Class III
Henry B. Washburn, of Class IV

Auditing Committee:

George R. Agassiz Alexander Forbes

House Committee:

Jerome C. Hunsaker, *Chairman*
William H. Lawrence Walter E. Clark
Robert P. Bigelow

Committee on Biographical Notices:
For Three Years:

Jeremiah D. M. Ford, *Chairman*
Hudson Hoagland

For Two Years:

James F. Norris Samuel E. Morison

For One Year:

Joseph H. Beale Alfred C. Lane

Committee on Meetings:

The President

The Recording Secretary

James R. Jack Abbott P. Usher
Tenney L. Davis Samuel H. Cross

The Corresponding Secretary announced that the following had been elected members of the Academy:

FELLOWS

Class I

Section 1. John Charles Duncan, Wellesley
E. Morton Jellinek, Worcester
Section 3. Emile Monnin Chamot, Ithaca, N. Y.
Robert Casad Hockett, Concord
Harold Clayton Urey, Leonia, N. J.
Section 4. Alfred Victor de Forest, Cambridge
John Moyes Lessells, Brookline

Class II

Section 1. Marland Pratt Billings, Boston
Section 2. Kenneth Vivian Thimann, Cambridge
Section 3. George Bernays Wislocki, Milton

Class III

Section 1. Henry Moore Bates, Ann Arbor, Mich.
Paul Drennan Cravath, New York, N. Y.
Robert Gray Dodge, Boston
Frank Washburn Grinnell, Boston
Melvin Maynard Johnson, Brookline
James McCauley Landis, Cambridge
James Madison Morton, Fall River
William Morton Prest, Boston
Bentley Wirt Warren, Boston
Section 3. Thomas North Whitehead, Cambridge
Section 4. Richard Evelyn Byrd, Boston
Edmund Ezra Day, Ithaca, N. Y.
Horace Sayford Ford, Belmont
Charles Seymour, New Haven, Conn.

Class IV

Section 1. Julius Seelye Bixler, Cambridge
Henry Sloane Coffin, New York, N. Y.
James Everett Frame, New York, N. Y.
Section 2. Allyn Bailey Forbes, Cambridge
Claude Moore Fuess, Andover
Stewart Mitchell, Boston
Bernadotte Everly Schmitt, Chicago, Ill.
Section 3. James Pyle Wickersham Crawford, Philadelphia, Pa.
Richmond Laurin Hawkins, Cambridge
Hyder Edward Rollins, Cambridge
Section 4. Joseph Hudnut, Boston
Howard Mumford Jones, Cambridge
Grenville Lindall Winthrop, Lenox

FOREIGN HONORARY MEMBERS

Class I

Section 3. Leopold Ruzicka, Zurich
Nevil Vincent Sidgwick, Oxford
Georges Urbain, Paris

Class II

Section 3. Edgar Douglas Adrian, Cambridge, England

Section 3. Sir Joseph Barcroft, Cambridge, England
Emmanuel Fauré-Frémiet, Paris

Class III

Section 1. William Warwick Buckland, Cambridge, England
Mircea Djuvara, Bucharest
Arthur Lehman Goodhart, Oxford
Rt. Hon. Lord Macmillan, London
Rt. Hon. Lord Wright, London
John C. H. Wu, Shanghai
Section 2. Dionisio Anzilotti, Rome
Kenzo Takayanagi, Tokyo
Section 4. Heinrich Bruening, Cambridge, Mass.

Class IV

Section 3. Ulrich Wilcken, Berlin

The following communication was presented:

Mr. George D. Birkhoff: "Mathematical Advances since 1900 and their Influence on Scientific Thought."

Two papers were read by title: "Epidemiological Studies on Measles with some Comparisons from Scarlet Fever and Infantile Paralysis," by Edwin B. Wilson and collaborators; "Studies on the Fauna of some Thermal Springs in the Dutch East Indies," by C. T. Brues.

The meeting was dissolved at 10.40 P. M.

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GEORGE PIERCE BAKER (1866–1935)

Fellow in Class IV, Section 4, 1914

George Pierce Baker was born on the fourth of April 1866, at Providence; he was graduated at Harvard in 1887, the next year was appointed instructor in English, was subsequently promoted to the professorship, and taught at Harvard from 1888 to 1924, when he accepted a call to Yale as Professor of the History and Technique of the Drama, and Head of the new University Theatre. He retired owing to ill-health in 1933.

In 1907–1908 he was James Hazen Hyde lecturer in Paris at the Sorbonne.

He was elected a member of the American Academy of Arts and Sciences in 1925.

In addition to his academic work at Harvard and at Yale, Professor Baker himself wrote and directed historical pageants in various towns in America, which are a contribution to our social history.

His most important books are "The Development of Shakespeare as a Dramatist," and "The Technique of the Drama."

From early childhood to the day of his death Professor Baker's chief interest was the art of the drama, and its relations with the theatre. When he began teaching in 1888, there were no opportunities offered at any university for the study of modern drama; and for many years Mr. Baker spent the major part of his time and energy in teaching English Composition, especially in the field of forensics. He performed this difficult task not only conscientiously, but with such energy that he elevated it almost to the position of a creative art. There are hundreds and hundreds of Harvard graduates who remember with gratitude and affection this prolonged grind in argumentative composition; for they came in later years to realize its value.

Fortunately for all concerned and certainly for his own spiritual welfare, he was from the start given a course in Elizabethan Drama, which field he had mastered as a scholar and taught as an apostle.

When I entered the Harvard Graduate School in 1890, I took this course, so that I have the honour of being enrolled among his pupils.

When he began to teach the art of play-construction, he made an academic number famous all over America—the number 47. The 47 Workshop was the title of the course directed and taught by Professor Baker; it was an absolutely practical course in the writing and stage production of plays. Students travelled from every part of the United States to become his pupils; many called but few were chosen. The numbers were ruthlessly kept down and only the elect were admitted.

Among these were Eugene O'Neill, Sidney Howard, Philip Barry, S. H. Berhman, playwrights; Winthrop Ames, Maurice Wertheim, Theresa Helburn, George Haight, Henry Potter, Kenneth McGowan, producers; many stage designers and dramatic critics, among whom is Walter Prichard Eaton. It should also be remembered that among those whom he advised *not* to write plays are Heywood Broun and Thomas Wolfe.

From this 47 Workshop flowed a spirit of passionate enthusiasm for the theatre, incarnate in many young students, who devoted their lives to it.

> Bliss was it in that dawn to be alive,
> But to be young was very heaven!

It is interesting to remember that the years of Professor Baker's career included the greatest period of British drama since the death of Shakespeare and the only period of importance in American drama.

W. L. Phelps

GEORGE ALBERT BOULENGER (1858–1937)

Foreign Honorary Member in Class II, Section 3, 1923

Doctor George Albert Boulenger was born in Brussels October 19, 1858 and died at St. Malo November 23, 1937.

After a short period of work in the National Natural History Museum at Brussels, Boulenger, at the invitation of Doctor Albert Gunther was invited to a post in the British Museum of Natural History in 1882. He continued in charge of the collection of reptiles and fishes in that institution until his retirement in 1920.

Boulenger was a man gifted with a most astounding energy and with a memory which was little short of amazing for during the years of his life in London no less than 875 papers flowed from his pen. Among his most important contributions to science were the long and detailed monographs published by the British Museum which, until they were superseded by a more refined taxonomic technic, remained a most useful foundation for much of the modern systematic work of the groups of animals concerning which he wrote. Among these monographs the following were noteworthy.

"Catalogue of Batrachians. . ." (2 vols., 1882), "Catalogue of Lizards. . . " (3 vols. 1885–87), "Catalogue of the Chelonians, Rhynchocephalians, and Crocodiles. . ." (1889), "Catalogue of the Snakes. . . " (3 vols., 1893–96), "Monograph of the Lacertidae" (1920), all published by the Museum; the volume on reptiles and batrachians in the Fauna of British India series (1890); and the monograph on the tailless batrachians of Europe, published by the Ray Society (1897–98). The first (and only) volume of a new edition of the "Catalogue of Fishes. . . " (1895), covering several important percoid families; "Les Poissons du Bassin du Congo" (1901); "Fishes of the Nile" (2 vols., 1907); the systematic section on the Teleostei in the "Cambridge Natural History" (1910); and "Catalogue of the Fresh-water Fishes of Africa . . . " (4 vols., 1909–15).

In spite of the fact that Boulenger worked on fishes, reptiles, and amphibians and allowing for certain idiosyncrasies concerning conceptions of nomenclature and taxonomic rank, his work was of an extraordinarily high quality. He had a keen appreciation of evaluating interrelationships and in many groups substituted a sound classification based on morphology and comparative anatomy where the previous systems had been based on external similarities.

He expressed himself easily and his writings are clear and concise. He seldom made a second draft of anything he wrote and his longhand manuscripts went straight to the printer. He was an excellent linguist and was a singularly charming and lovable character.

As a small boy he was passionately fond of wild flowers and on his retirement at the age of 63 he dropped zoology completely and attached himself to the Botanical Gardens in Brussels where he undertook a monographic study of the European roses based largely on the excellent herbarium of Francois Crépin. Two volumes have already appeared under the title of "Les Roses d'Europe de L'Herbier Crépin."

Boulenger was elected to the Royal Society in 1894; served on the Council of the Zoological Society from 1893–1911. He received the Honorary Doctorate from Louvain, Giessen and St. Andrews and a silver medal from the Société d'Acclimatation in Paris. In 1935 the American Society of Ichthyologists and Herpetologists elected him its first Honorary Member and in 1937 the King of Belgium conferred upon him the Order of Leopold.

He became a naturalized Englishman.

THOMAS BARBOUR

INGERSOLL BOWDITCH (1875–1938)

Fellow in Class III, Section 2, 1924

Ingersoll Bowditch was born in Jamaica Plain May 31, 1875, and died there on February 11, 1938. He was the son of Charles Pickering Bowditch and Cornelia (Rockwell) Bowditch. He held the degree of A.B. from Harvard (1897) and the S.B. from Massachusetts Institute of Technology (1900). He was the fourth Bowditch in direct line to hold membership in the American Academy. His great grandfather, Nathaniel Bowditch, was the fifth President, succeeding John Quincy Adams in 1829, his grandfather, J. Ingersoll Bowditch, was Treasurer, and his father, Charles P. Bowditch, was Treasurer from 1905 to 1915 and President from 1917 to 1919. Ingersoll Bowditch was elected to the Academy in 1924 and served as Treasurer from that time until his death.

Trained as an engineer, he soon abandoned this profession to follow the family tradition of the management of estates and property, in addition to membership on many and various boards and committees of academic and benevolent institutions.

For many years he made hospital management and finance his main interest outside his vocation. He was President of the Sharon Sanatorium, Vice President of the Boston Hospital Council, Treasurer of Faulkner Hospital, and the Associated Hospital Service. He had also served as Treasurer of the Jamaica Plain Dispensary, the

Instructive District Nursing Association, and manager of the Corporation of Adams Nervine. He was a member of the Corporation of Perkins Institute and also one of the editors of "Hospital Management." An editorial in this publication shows clearly and unmistakably the place he held in the field of hospital administration: "Mr. Bowditch has become of such service to the entire hospital field that his passing is keenly felt by all of us who have an interest in national hospital affairs. . . . His deep interest in all hospital problems and his unselfish willingness to contribute time and diligent application to national hospital problems made him probably the leading hospital trustee in the country."

He was the fourth Bowditch in direct succession to serve as an officer of the Massachusetts Hospital Life Insurance Company. He was Trustee of the Eliot School and a member of the Overseers Committee of Harvard University to visit the Arnold Arboretum. During the incumbency of his cousin, Edward Pickering, as Director of the Harvard Observatory, he was a member of the Overseers' Committee of that institution. From 1911 he was a member of the Alumni Council of Technology, representing his class on this Council since 1913. He was a Director of the State Street Trust Company, of the Massachusetts Cotton Mills, and of the New England Lumberman's Association, and for a time Treasurer of the Society for the Advancement of Colored People.

It was exactly fifty years ago that the Bowditch name became intimately associated with the Peabody Museum of Harvard University. On the death of his father in 1921, Ingersoll succeeded him as a member of the Faculty and became a valued member of that body. His first connection with the Museum was in 1897 when he accompanied Dr. Swanton and Dr. Dixon on an expedition to Madisonville, Ohio, where he made a survey and plan of the famous aboriginal cemetery there. He succeeded his father as one of the Trustees of the Hopkins Fund, one of the earliest charities to be established in the colony. Edward Hopkins, dying in 1657, left a sum of money "for the breeding up Hopefull youth in the way of Learning both at ye Gramar School and Colledge for the Publick Service of the Country in future times."

Mr. Bowditch's unselfishness and willingness to serve his fellow man is seen in his associations in Chocorua, New Hampshire. The large family holdings there were only a means to an end. Constantly he endeavored to institute lucrative employment for the villagers. Growing up as a boy with them, he was accepted as one of them and his wise counsel was constantly being sought not only in relation to the affairs of the village as a whole, but also in the private lives of many of its citizens. He was one of the five trustees of the newly organized Tamworth Foundation.

He is survived by his wife, Sylvia Church (Scudder) Bowditch, Bryn Mawr, 1899; Samuel I. Bowditch, Harvard A.B., 1928; S.D., 1935; Sylvia C., Bryn Mawr, 1933, and Charles P., Harvard ex-1936.

Boston has lost one of its most unobtrusive, but most serviceable, unselfish, fair-minded, and kindly citizens.

Alfred M. Tozzer

FRANTZ DAHL (1869–1937)

Foreign Honorary Member in Class III, Section 1, 1933

Frantz Dahl, statesman, jurist, judge, legal historian, professor of the history of jurisprudence in the University of Copenhagen, was born in Copenhagen October 23, 1869. His father was court watchmaker. He was educated at the University of Copenhagen and afterward studied at Halle under Franz von Liszt, the great criminalist, with whom, as an inspired student, he formed an enduring friendship. He entered the civil service in 1896 as Assistant Secretary in the Ministry of Public Worship and Education. In 1905 he became substitute superior judge in Viborg, and in 1906–1907 in Copenhagen. In 1910 he was made reporting councillor in the Ministry of Public Worship and Education, and from 1916 to 1919 was Ministerial Director of the Ministry of State and Secretary of State. He was censor in state bar examinations from 1910 to 1919 and Associate Professor of Criminal Law in the University of Copenhagen 1914–1919. In 1919 he was appointed to a chair of History of Jurisprudence created for him specially. In addition, he was one of the directors of the New Carlsberg Glyptotek (1909), President of the Jury of the Royal Theatre (1913), President of the Place Names Commission (1914), President of the People's University Commission, Juristic Adviser to the Royal Library, co-editor of the Danish Journal of Jurisprudence (Tidskrift for Retsvidenskap) 1918–1936, and of the Archiv für Beiträge zum deutschen, schweizerischen und skandinavischen Privatrechts. He was a contributor to periodicals, and cyclopaedias in many languages, including the Encyclopaedia of the Social Sciences published in America. Many honors came to him from abroad, for example, an honorary doctorate from the University of Hamburg in 1921, corresponding membership in the Institut de droit comparé (Brussels) and in the Institut intermédiaire international (The Hague).

In addition to literally hundreds of biographies, essays, and reviews, chiefly of juristic interest, and editions of the Danish Criminal Code, a commentary, (5ed. 1926), and of a text book of Roman Law (1937), his more important books are: "Juridiske Profiler" (Sketches of Twelve Great Jurists, 1920); "Frederik VI og Anders Sandöe Oersted i 1826" (1929); "Anders Sandöe Oersted som Retslaerd" (1927, translated into English and into French); and "Hovedpunkter af den danske Retsvidenskaps Historie" (Main Points of the History of Jurisprudence in Denmark, 1936). This, to be sure, is not a long list of books. But what is lacking in quantity is much more than made up in quality.

Frantz Dahl, though his first concern was with the history of jurisprudence, for which, as has been said, a professorship was specially set up for him, was a scholar of the widest interest. Philosophy, aesthetics, and philology were in his field also and his reading was exceptionally extensive in all languages. His acquaintance with jurisprudence and the history of the science of law was complete and thorough; but his juristic activities went beyond the law to the historical and cultural research which makes a science of law fruitful.

As a teacher, Frantz Dahl is said to have been helpfulness personified. Students, junior teachers, and older jurists alike turned to him continually, and found what they had need of in his wise suggestions from the depth of his insight and the breadth of his learning. He was an inspiring teacher, especially in Roman Law, and his relations with students were of the best. He died December 21, 1937.

Roscoe Pound.

VICTOR LALOUX (1850–1937)

Foreign Honorary Member in Class IV, Section 4, 1927

Victor Laloux, architect and teacher, was born at Tours, France, on November 15th, 1850. Passing successfully through the École des Beaux Arts as a student in the atelier of Jules André, to whom he was devotedly attached, he received his diploma as architect in 1877 and was awarded the Grand Prix de Rome in 1878.

The privileges of travel inherent in this coveted prize opened wide the doors of opportunity, revealing to Laloux successively the wealth and richness of the Italian Renaissance and the simple beauty of Greek Architecture. His maturing powers responded eagerly to Palladio's masterpieces, but at Olympia he found a challenging opportunity that called forth the highest qualities of spirit and mind. In contrast to the magnificence of the Italian Renaissance, he finds "La pure beauté des antiquités grecques apparaît à mes yeux comme une 'embellie' qui succéderaient au tumulte de la tempête."

From 1880 to 1883 he travelled extensively throughout Italy and Greece. Travelling by preference alone, he followed the development of his own ideas undisturbed by conflicting suggestions. It was during this period that he prepared drawings showing, among others, restorations of the Temple of Venus at Rome and of the sacred precincts at Olympia. These revealed such an outstanding grasp, not only of details, but of the animating spirit of the period that he became a recognized authority qualified by knowledge and insight to reestablish the connection between the ancient faith of this classic past and the beliefs of our modern times.

Two events that profoundly affected his later life occurred in the years immediately following his return to France. In 1885 he married Mlle. Camille Monthtiers, and in 1890, following the death of his friend and patron Jules André in the previous winter, he was chosen by the students to become head of the new Atelier Laloux. It was during this period also that he published his "History of Greek Architecture" and his important work on Olympia, for which the text was prepared by Paul Monceaux.

Mme. Laloux supplemented with rare grace and sympathetic hospitality the instinctively generous friendliness that characterized Laloux's relations with his fellow artists. Their salon became a center for lovers of the Arts: painters, sculptors, musicians, engravers gathered under their roof to share their common interests and to establish relations that bore fruit in the work that was so soon to determine Laloux's preeminence among the architects of his time.

The following quarter century was the golden age of Laloux's professional accomplishment. As architect and teacher these years brought him the fullest measure of recognition. It was during these years that he built the Basilica of St. Martin at Tours, the great railroad stations on the Quai d'Orsay in Paris and again in Tours. Later came the Hôtels de Ville at Tours and at Roubaix and the central offices of the Crédit Lyonnais in Paris. Meanwhile his atelier became famous for the success of its students in the regular exercises of the École des Beaux Arts and in winning the Grand Prix de Rome. American students flocked to his criticism and contributed their share to the honors won under his guidance. In 1909 he was elected member of the Institut de France and later Commander and Grand Officier of the Légion d'Honneur. He was President successively of the Societé des Artistes Français, des Architects diplomés par le Gouvernement, and of the Societé Centrale des Architects. From America he received the Gold Medal of The American Institute of Architects and from England the Gold Medal of the Royal Institute of British Architects. He was Inspecteur Général Honoraire des Bâtiments Civils et Palais Nationaux.

From the end of the Great War until his death on July 13th, 1937, Victor Laloux devoted himself to the criticism of his students for the Grand Prix de Rome. As advancing years increasingly limited his activities it was his great pleasure to welcome to his apartment on the rue Solférino in Paris or at the "Marjolaine" near Fontainebleau the hosts of friends and former students who sought his counsel and treasured his friendship.

His architecture like his criticism was characterized by breadth and vigor. Based upon the soundest knowledge of tradition, it evolved through the strength of his own personality and a comprehensive grasp of the essentials inherent in every problem. The scheme, the basic principle, of his designs interested him more than the details—he was indeed a Masterbuilder.

William Emerson

FREDERIC BREWSTER LOOMIS
(1873–1937)

Fellow in Class II, Section 1, 1917

Frederic Brewster Loomis was born in Brooklyn, New York, November 22, 1873. In 1892 he entered Amherst as a freshman and began an association with that institution which, except for two years of graduate study, continued until his sudden death on July 28, 1937.

In his youth he became interested in natural history; this interest was intensified by study at Amherst under Tyler the biologist, and Emerson the geologist. Loomis soon decided that vertebrate paleontology was the field of major interest to him. Following his graduation and a postgraduate year as assistant in biology at Amherst, he went to Munich where he obtained his doctorate in his chosen field under von Zittel. He returned to Amherst in 1899. During the following 18 years he was a member of the Biology department as instructor, associate professor, and from 1908, Professor of Comparative Anatomy. In 1917 the post of Professor of Geology became vacant upon the retirement of Professor Emerson, and for the last 20 years of his life Loomis was in charge of geological teaching. It is a matter of pride to the college that in a full century the chair of geology was occupied by but three men—Hitchcock, Emerson, and Loomis—all of whom were eminent in their fields.

He was an indefatigable collector of fossil mammals. Commencing in 1903 he undertook the first of a series of 15 field trips to the western fossil beds on behalf of the college. In addition to these western trips, an expedition to Patagonia in 1911 added a fine series of mammals from that region including the unique skull of the Oligocene *Pyrotherium;* additional expeditions gathered materials from the prehistoric shell heaps of Maine and the Pleistocene deposits of Florida. As a result of these collecting trips and the faithful labors of the veteran preparator, John Harlow, Amherst has a splendid array of fossil vertebrates. Its exhibits are excelled by only a few of the larger museums. They include what is perhaps the best exhibition illustrating the evolution of the horses, and fine series of fossil camels, oreodonts, cats, and dogs.

Most of Loomis' publications, numbering about 75 titles, are based upon his studies of these collections. Apart from papers in various scientific journals, he was the author of five books. Two deal with his Patagonian expedition, and a third with the evolution of the horse family. The other two are texts, one a widely-used manual of common rocks and minerals, the other, published just before his death, a physiography of the United States.

A man of extraordinary activity and industry, Loomis did not confine his interests to his scientific specialty. He was a highly successful teacher. He had none of the tricks of the professional orator, but his enthusiasm for the subjects which he taught won him the respect and love of many generations of elementary students; his success in more advanced work is witnessed by a long list of biologists and geologists who owe the initiation of their scientific careers to the interest generated by him. He was active in college affairs, and was Vice-President at the time of his death. He was a moving spirit in the faculty science club and the college outing club, and retained an active interest in his undergraduate fraternity chapter. His family life was a happy one. Mrs. Loomis (neé Florence C. Calhoun) and his two sons, Newell Calhoun and Frederic Brewster, all of whom survive him, often accompanied him on his western trips. Among his fellow workers in paleontology he was exceedingly popular not merely for his scientific attainments but for his warmth of character. He was president of the Paleontological Society in 1920 and retained throughout his life an active interest in the meetings of the vertebrate section of the Society. By his death his paleontological colleagues were deprived not merely of a distinguished scientist but of the best-loved member of their group.

A. S. Romer

OGDEN LIVINGSTON MILLS
(1884–1937)

Fellow in Class III, Section 2, 1932

Ogden L. Mills was born at Newport, Rhode Island, August 23, 1884. He was the son of Ogden and Ruth T. (Livingston) Mills, and on both sides of his family was the heir to a distinguished name and a large fortune. He was educated at Harvard, where he received his A.B. degree in 1905 and his LL.B. in 1907. Prominent in the social life of the College, he did not distinguish himself as a scholar or give striking promise of the extraordinarily useful career which lay ahead of him. His family connections enabled him to take an assured place in the business and social life of New York City, where he joined the leading clubs and lent his name to the directorates of important business corporations. Responding to the claims which the community customarily makes upon such favorites of fortune, he also became a trustee of the Provident Loan Society, of the American Museum of Natural History, and of the East Side House Settlement.

Extraordinary energy, intellectual vigor, and public spirit made Mills unwilling to acquiesce in the conventional life of ease and elegance to which he might have seemed destined by his position as an hereditary metropolitan capitalist. In 1911 he became treasurer of the Republican County Committee, a position which he continued to hold for fifteen years, and in the following year he was an unsuccessful Republican candidate for election to Congress. Two years later he was elected to the New York State Senate, to which he was reelected in 1916. At this stage of his career he also found time to serve for several years as president of the New York State Tax Association and as chairman of the Committee on an Executive Budget of the National Tax Association. When the United States entered the World War he was commissioned a captain in the national army and served with the A. E. F. in France from January, 1918, to March, 1919. Upon his return he renewed his political activity with freshened zeal and was elected to represent New York's Fifth Avenue district in three successive Congresses, serving from 1921 to 1926. He retired from Congress to run against Alfred E. Smith for governor of New York, thereby helping to build up his opponent as a candidate for the presidency. Appointed Undersecretary of the Treasury in 1927, he succeeded Andrew W. Mellon five years later as Secretary of the Treasury, too late to rescue the Hoover Administration from its misfortunes. His book, "What of Tomorrow," published in 1935, attests his continued devotion to the problems of American government.

Mills developed a deep interest in education as well as in politics. He gave many years of service to his *alma mater* as a member of standing committees of the Board of Overseers to visit the Departments of Government and Economics, and became one of the stoutest advocates of the liberal policies traditionally associated with the management of Harvard University. Quotations from a letter to a personal friend, written December 3, 1936, and expressing his mature opinion on the vexatious question of academic freedom, best reveal the trend of his thinking and the quality of his mind.

"I have been thinking over our conversation," he wrote, "with reference to the reluctance of some Harvard men to contribute to the Tercentenary Endowment Fund because of alleged radicalism in the University, and of the outside activities of certain members of the Faculty. The more I think of it, the more I am satisfied that such an attitude is unjustified. As I understand it, the outside activities complained of consist of unofficial participation in the formulation of those policies of government which have come to be known as the 'New Deal', and more particularly of the advocacy of certain measures that in the opinion of many run counter to the form and spirit of our institutions.

"No one has opposed these measures more strongly than I have, or been more critical of much of the New Deal. But if a member of the Harvard faculty is called upon to advise his Government, I can not for the life of me see what else he can do save respond. And surely, if he does advise, he must speak according to his own conscience and convictions. Certainly he should not endeavor to present what he conceives to be the views of the Corporation or the alumni. He has no right to speak for them. He is not in any sense their representative. He is acting outside the scope of his professional duties, and in his own time, as a private citizen whose opinion is valued by those in authority.

"A teacher has as much right to engage in outside activities and to express his views on public questions, as any other professional man. That his views may not coincide with those of a governing board, or do violence to the convictions of the great body of graduates, may be unfortunate, but to ask him to remain silent unless his opinions conform to theirs, would be to limit his rights as a citizen, to deprive him of part of his liberty, and to impose humiliating restrictions unacceptable to independent and high-minded men. Any University attempting to enforce such a censorship would soon cease to attract preeminent men who combine independence of mind with sound scholarship, the very men who bring it strength and vitality. It would thus pay a penalty so heavy as to make any temporary embarrassment or irritation occasioned by the words or activities of an individual, however imprudent, seem conparatively trivial . . "

The whole of this letter, which in its entirety forms an admirable statement of the substance of the liberal tradition respecting academic freedom, was published in the Bulletin of the American Association of University Professors (vol. xxxiii, no. 8, December, 1937). It constitutes an impressive revelation of the essentially liberal spirit of a conservative gentleman and statesman. Mills' death on October 11, 1937, brought to an untimely close a useful life, which incidentally illustrated with uncommon clarity the beneficent results of liberal education for citizenship in a democracy.

ARTHUR N. HOLCOMBE

FRANK MORLEY (1860–1937)

Fellow in Class I, Section 1, 1917

With the death of Professor Frank Morley mathematics and this country lost an outstanding personality.

Born in Woodbridge, Suffolk, England on September 9, 1860, the son of Joseph R. and Elizabeth Morley, he took his A.B. degree at King's College, Cambridge, in 1884, his A.M. in 1887, and received the degree of Sc.D. from the same university in 1898. From 1884 to 1887 he served as master in Bath College, England.

His mathematical career in America began with an appointment as instructor in mathematics at Haverford College in 1887. The following year he was promoted to a professorship and remained in that position until he was called to head the Department of Mathematics at Johns Hopkins in 1900.

While at Haverford Professor Morley cooperated with James Harkness of Bryn Mawr in the publication of two books on theory of functions. The first of these, "A Treatise on the Theory of Functions," appeared in 1893 and in 1898 was followed by their "Introduction to the Theory of Analytic Functions." In a period when mathematical analysis in England and America was still mainly formal, these books served as a most valuable introduction to the rigorous methods of the continental mathematicians.

At Johns Hopkins his principal interest was in algebraic and projective geometry and particularly in metrical properties projectively related to the imaginary absolute. He usually lectured four or five times per week to a class consisting of all the graduate students in the Department. The first year students of course understood very little of what was said. When they complained of this he merely assured them that they would understand more next year. After hearing the same, but never precisely the same, lectures for four years, the student usually found that at some time, but he didn't know precisely when, the subject matter had become entirely clear.

As a lecturer Professor Morley was usually humorous but did not appear particularly enthusiastic or excited about what he was saying. He had the rare faculty, however, of making the student extremely curious to know more about almost anything he mentioned.

Professor Morley was a member of the New York Mathematical Society, and of its successor, the American Mathematical Society from about the time of its organization. He was vice-president of the American Mathematical Society in 1902 and president during 1919 and 1920. He was a member of the London Mathematical Society, the Circolo Matematico di Palermo, the American Philosophical Society, the American Academy of Arts and Sciences, and from 1900 to 1921, was editor of the American Journal of Mathematics.

On July 11, 1889 he married Lilian Janet Bird of Hayward's Heath, Sussex, England. They had three sons, all born at Haverford. All three brothers held Rhodes Scholarships at New College, Oxford, and all three have attained distinction in literature. They are Christopher Morley, the well-known novelist; Felix Morley, Editor of the Washington Post; and Frank V. Morley, a Ph.D. in mathematics of Oxford University, now an author and publisher with headquarters in London.

In 1928 Professor Morley retired as professor emeritus and on October 17, 1937 died at his home in Baltimore. A long line of graduate students remember him not only as a great teacher, but as a great friend and counselor, as a great man.

H. B. Phillips

GEORGE HENRY FALKINER NUTTALL
(1862–1937)

Foreign Honorary Member in Class II, Section 3 (1919)

Dr. Nuttall was born in San Francisco, the son of a pioneer physician, Dr. Robert K. Nuttall. His sister, Zelia Nuttall, is an archaeologist, widely known for her investigations in Mexican archaeology. The family moved to Europe, living for a time in England, France, Germany, and Switzerland. Here as a lad Nuttall received his early education and laid the foundations for his well-known linguistic accomplishments.

He later returned to California, entered the University of California Medical School, and received from it the degree of M.D. in 1884. After a brief attendance at Johns Hopkins Medical School he returned to Europe and studied at Breslau, and at Göttingen, where he received the degree of Ph.D. in Zoology. These studies laid the foundation for his later interest in parasitology in which field his life work subsequently developed. He was back again in Baltimore in 1890 as assistant to Professor William H. Welch and latter as Associate in Hygiene. After four years on the staff at Johns Hopkins Medical School he went in 1893 to the Hygienic Institute at Berlin where he served as honorary assistant to Professor Rubner. In 1895 he married Paula, daughter of Kammerherr von Oertzen-Kittendorf. She died in 1922.

In 1899 Nuttall went to Cambridge, England, to teach bacteriology and preventive medicine in the University and was appointed University Lecturer in these subjects in 1900, receiving the honorary M.A. degree. In 1906 he was appointed Reader in Hygiene, obtained the degree of Sc.D., and was elected Fellow of Christ's College. His readership was of brief duration since only a few days after this appointment he was elected to the newly established Quick Professorship of Biology and to a professional fellowship in Magdalen College. The Quick Department was devoted to his favorite field of Parasitology and his work was carried on from 1907 to 1920 in the Quick Laboratory, a single crowded room divided up into alcoves by cupboards and screens. But these physical limitations did not reduce his activities. Release from these crowded surroundings came with the gift of £30,000 by the late Mr. and Mrs. Molteno in 1919, which provided for the erection of the Molteno Institute for Research in Parasitology where his work continued till his retirement in 1932.

Honors came to him both in England and from abroad. He received many honorary degrees. In addition to the honorary M.A. from Cambridge in 1900, he received honorary LL.D. from the University of California in 1924, honorary Doctor from the University of Strasbourg in 1927, honorary M.D. from Egyptian University in 1928, and from University of Liège in 1930, and honorary D.SC. from the University of South Africa in 1929. He was elected Fellow of the Royal Society of London along with his friend A. E. Shipley of Cambridge in 1904. He was Foreign Honorary Member of the American Academy of Arts and Sciences; Corresponding Member of the Royal Academy of Medicine of Turin, of the Société de Pathologie Exotique, Paris, of the Société de Biologie, Paris, of the Society of American Bacteriologists, of the American Entomological Society, and of the Academy of Medicine, Paris; Honorary Member of the American Society of Tropical Medicine, of the Royal Society of Medicine, Budapest, of the Microbiological Society, Leningrad, of the Harvey Society, New York, of the Boston Society of Natural History, and of the American Society of Parasitologists. He was awarded the Belgian Order of Leopold II and the French distinction of Commandeur de la Légion d'Honneur. He was late Associate in Hygiene and sometime Herter Lecturer of Johns Hopkins University. He was Member of the Army Pathology Advisory Committee (War Office) and of the Imperial Bureau of Entomology (Colonial Office).

Nuttall's researches carried him into many fields but his aim was maintained with singular pertinacity toward the biological interpretation of the phenomenon of disease. They include over two hundred published papers and books in the fields of bacteriology, serology, hygiene, preventive medicine, tropical medicine, and parasitology. Because of this very diversity of themes it is difficult for any one person to assess with equal justice to all of them the relative values of his various contributions.

An outstanding achievement among them is undoubtedly his discovery that the blood and some other fluids of the body have a bactericidal property, a discovery which laid the foundations for later work on serum antitoxins. His monograph on "Blood Immunity and Blood Relationship" (1904) not only developed the subject of precipitin reactions but also established the existence of subtle and pervading chemical specificities in the blood of all individuals of a species, and also degrees of relationships in blood patterns of species indicative of phylogenetic derivations and consanguinity. The precipitin reactions which he analysed have come to be widely used in forensic medicine. An interesting biological application of this method is its recent use in determining the feeding preferences of the malarial mosquito by the precipitin reaction of her last meal. In collaboration with Welch (1892) he discovered the pathogenic gas producing bacillus causing gas-gangrene, a work contributing greatly to medical service to wounded men during and following the Great War. His other bacteriological work concerned diphtheria and especially hygienic measures in relation to infectious diseases. In collaboration with Thierfelder (1895–97) he carried out the first successful aseptic experiment in rearing bacteria-free guinea pigs delivered by Caesarian operation. This technique made possible the accurate determination of the origin of certain biochemical substances in faeces and urine.

His investigations in the field of animal parasitology are quite naturally confined largely to blood-feeding arthropods. They include the first map of the distribution of the malarial mosquito, *Anopheles maculipennis*, in England showing a marked conicidence with the outbreaks of malaria; a study of the biology and anatomy of this vector of malaria with Sir Arthur Shipley; an extensive investigation of the anatomy, life history, biology, and systematics of ticks; and an intensive study of lice carried on during the war. Correlated with his study of ticks was his investigation of piroplasmosis in dogs, a disease caused by a protozoan parasitic in red blood cells, whose insect vector is a tick. A valuable by-product of this study was his discovery that trypan blue has curative properties for this disease in dogs, sheep, and cattle.

Nuttall founded the *Journal of Hygiene* in 1901, and *Parasitology* in 1908, editing both and maintaining consistently a high standard both in content and illustration. These journals and his own varied investigations did much to develop interest in parasitology in the medical profession and to extend the scope and raise standards in the field of tropical medicine which grew rapidly during his lifetime.

Personally he was a man of social charm, a brilliant conversationalist and raconteur. His linguistic abilities made him a center at all international congresses and his laboratory was a mecca of visiting colleagues. His wide acquaintanceship made it feasible for him to acquire the remarkable collection of photographs of parasitologists which adorn the walls of the Molteno Institute. His colleagues and pupils presented him on his retirement in 1932 with his portrait in oils painted by the late Philip de Laszló. He died suddenly December 16, 1937, at the age of seventy-five years.

Charles A. Kofoid

FRANCIS GREENWOOD PEABODY
(1847–1936)

Fellow in Class IV, Section 1, 1918

Francis Greenwood Peabody was born in Boston on December 4, 1847, the son of Ephraim and Mary Jane (Derby) Peabody. He began life with a formidable inheritance to live up to: his father was minister of King's Chapel; he himself was named for his father's predecessor, Rev. Francis Greenwood; his mother was a member of the famous Derby family of Salem. Fortunately there were other elements in his inheritance which enabled him not only to meet these exactions, but to raise the fame of his family to even higher levels. He graduated from Harvard in 1869, and from the Harvard Divinity School in 1872, with the degrees of S.T.B. and A.M. Shortly after graduating from the Divinity School, he married Miss Cora Weld of Boston. After eighteen months of travel, most of which was spent in study at the University of Halle, he accepted a call to the First Parish in Cambridge, and was ordained on March 31, 1874.

Religion was a potent factor in his life; as we say, he took it seriously. In few men have the disparities between religious profession and practice been so inconspicuous. To his conscientious nature, Emerson's adage, "Go put your creed into your deed," was an ever-active command. This very conscientiousness played havoc with his health as a parish minister. Every Sunday was a spiritual and emotional ordeal which left him exhausted; and after five years in the ministry, he had to resign because of ill-health.

At once however he found his true *metier* in teaching. In 1880 he was appointed lecturer on Ethics and Homiletics at Harvard; and in 1881, Parkman Professor of Theology. In 1886 he became Plummer Professor of Christian Morals with supervision of the College Chapel, and this office he held until his retirement from active work in 1913. Both the amount and the quality of his achievements bear evidence to the congeniality of this office. He proved himself the right man in the right place, and became a worthy successor to the beloved Andrew Preston Peabody who had preceded him as Plummer Professor. Four of his books: "Jesus Christ and the Social Question," "Jesus Christ and Christian Character," "The Approach to the Social Question," and "The Christian Life in the Modern World," contain the substance of his teachings on Christian morals, and reveal him as a pioneer in the application of Christ's precepts to the larger field of man's social relations. At the same time various of his published Appleton Chapel talks, notably "Mornings," and "Afternoons," and

"Evenings in the College Chapel," indicate the high standard he established for the conduct of religious service in that famous house of worship.

The winter of 1905–6 he spent in Berlin as the first exchange professor from America; and in him that institution of exchange professorships was most auspiciously inaugurated. He won wide recognition, and made a host of friends among the scholars and statesmen of Germany. His writings are all marked by conspicuous literary beauty and finish. As a preacher the same quality of literary grace, dignity, and beauty was so noticeable, that, as in the case of Tennyson, it almost disguised the depth and power of his thought and spiritual insight. He was proud of being a good workman; he delighted to see thorough craftsmanship in others; he was instant, in season and out, in teaching good craftsmanship to his young men. As one of his countless admirers, Rev. Paul Revere Frothingham, said at the complimentary dinner given him when he retired: "When it comes to preaching, it is Peabody or nobody." Needless to say, he was in great demand all over the country, at college chapels, inaugurations, ordinations, anniversaries, and the like. One of his favorite interests was Hampton Institute in Virginia. For many years he served as trustee, and vice-chairman of trustees of that noble institution, and was a familiar and honored figure on its campus.

The last twenty-odd years of his life were singularly happy and busy. There were two great sorrows; the death of his wife, and the death of his son, Dr. Francis W. Peabody. Both of these occasions were sublimated by his serene faith into experiences of an unearthly tenderness. His industry never flagged. Some of the books written during this period of retirement: "Reminiscences of Present-Day Saints," memories of the famous men he had known, "A New England Courtship," a brief biography of his parents, "The Privileges of Old Age," and others, show how sensitive he was to all that is noble and true in human nature, and how retentive were his grateful recollections of those who had enriched his own mind and heart. He died at his home in Cambridge on December 28, 1936, just at the beginning of his ninetieth year.

Charles E. Park

WILLIAM HENRY PICKERING

(1858–1938)

Fellow in Class I, Section 1, [1883] 1899

The life of William Henry Pickering covered what has probably been the most significant transition period in astronomy since the introduction of the telescope. He was born in Boston on February 15, 1858, and graduated from the Massachusetts Institute of Technology at the age of twenty-one. He began his long career of astronomical research at the Harvard Observatory, where his brother, Edward C. Pickering, was director, in 1883, at which time the practical application of photographic techniques to astronomy was in its beginning phase. Although attempts had been made to photograph stars as much as twenty years earlier, it was the recent development of the dry plate that made a large-scale program of astronomical photography possible. William Pickering was quick to see the enormous importance of such photography, and he was instrumental in starting the systematic recording of the sky in this fashion.

William Pickering travelled to many parts of the world to observe and record total solar eclipses. His major contributions to astronomy, however, lay in his study of planets; and he became, especially, one of the leading authorities in the observation of Mars. For many years he carefully watched and analyzed the famous "canals" that offered such baffling material for speculation. His observations of Mars were published in a series of forty-four monthly articles appearing in "Popular Astronomy" between the years 1914 and 1930. At the time of his death he had nearly completed a new composite map of Mars.

Pickering was also an active observer of other planets, and of the moon. He discovered the ninth satellite of Saturn on plates taken, in a program which he designed for that purpose, with the 24-inch doublet at the southern station of the Harvard Observatory, which was set up in 1891 in Peru. His computations of the orbit of the satellite, which was named Phoebe, proved, much to his amazement, that this body was revolving in a retrograde orbit—the only object known in the solar system that was moving in such fashion. For many years Pickering worked on a study of the moon, most of his observations being made at the observatory which he established at Mandeville, on the island of Jamaica. From photographs taken there he published, in 1903, the "Photographic Atlas of the Moon," containing eighty plates and forming the most complete study of the satellite up to that time.

Prominent in his many investigations of the planets is Pickering's work on a possible trans-Neptunian planet. In 1907 he published his first important paper on the prediction of such an object, the result of his studies of the perturbations of the orbit of Uranus. Twelve years later he gave a position for the trans-Neptunian planet which was found, when Pluto was finally discovered in 1930, to be very nearly that of the newly identified body.

Pickering became permanently established at the Jamaica branch of the Harvard Observatory in 1912. After his retirement in 1924 he continued his work there, maintaining the station as a private observatory. During his long period of residence in Jamaica he made visits to America and Europe, and retained a lively and fruitful interest in many problems in addition to his principal studies. He wrote on the changes in the spectra of developing novae, and was the first to suggest the rocking-mirror method of determining meteor velocities, which was later used with much success.

William Pickering died at Mandeville on January 17, 1938. He is survived by his widow and two children.

HARLOW SHAPLEY

JOHN OSBORNE SUMNER (1863–1938)

Fellow in Class IV, Section 2, 1916

John Osborne Sumner, Professor Emeritus in the School of Architecture at the Massachusetts Institute of Technology, died suddenly at his home in Boston, February 20, 1938.

Mr. Sumner was born in Boston on November 23, 1863. He attended Harvard and received his bachelor's degree in 1887. He then studied at the Harvard Graduate School, engaged principally in research concerning the political history of the Confederate States.

After traveling in England, France, and Switzerland, he continued the study of History and Philosophy at the University of Berlin. The autumn of 1889 found him back in America, registered once more at Harvard for graduate study and research.

From the spring of 1890 until the autumn of 1893 he was abroad studying at the University of Berlin and for brief periods at other universities in Germany and Switzerland.

In 1894, returning to America because of serious trouble with his eyes, he became instructor at the Massachusetts Institute of Technology in the Department of History. He was appointed Assistant Professor of History in 1897 and received a full professorship in 1907.

When the Department of History was discontinued in 1919 Professor Sumner was transferred to the School of Architecture where for some years had lain his main interest, focussed upon his course in European Civilization and Art; a course extending from the beginning of the third through the graduate year and taken by all students studying Architecture. In the most painstaking development of this work he found an unfailing and ever growing sphere of interest. His love for the subject proved contagious. Few indeed were the members of his classes who failed to realize that a new and entrancing field of cultural interest had been opened to them, and fewer still are those who do not feel his firm but kindly personality as a profound influence in their lives and thoughts.

Mr. Sumner was married in May 1900 to Mary Shreve Hutchinson of Philadelphia who died in 1915 leaving him three sons.

In June 1921 he married Margaret Paulding of New York.

He was a member of the Massachusetts Historical Society, a member of the American Archaeological Institute, being Vice-president of the Boston Society, and a member of the St. Botolph Club of Boston, the Harvard Club of Boston and of New York. In January 12, 1916 he was elected a Fellow of the American Society of Arts and Sciences. He served as Chairman of the house committee from 1920 to 1924.

W. H. LAWRENCE

SIR ARNOLD THEILER (1867–1936)

Foreign Honorary Member in Class II, Section 4, 1929

Sir Arnold Theiler was born in Switzerland on March 26, 1867. At the age of twenty-four after completing his training in veterinary medicine, he left his native country to settle in the Transvaal where he spent most of his working years. His ability was soon recognized through his contributions to veterinary science and he was appointed Veterinary Surgeon for the Republic in 1896 by President Kruger in which capacity he served until 1900. From this time he worked as government bacteriologist until 1910 when he was appointed Director of Veterinary Research for the Union of South Africa. During his government service he created the Onderstepoort Institute of which he was director for more than a quarter of a century. His sudden death occurred in London on July 24, 1936.

The magnitude of the problems and the wealth of material which South Africa presented to Dr. Theiler would doubtless have overwhelmed one not endowed with his tireless energy and unusual ability. Early in his career he was able to demonstrate anaplasmosis as a distinct infection, it having been previously confused with piroplasmosis owing to the common occurrence of the two in mixed infection. His contributions to the knowledge of this group of diseases are of major importance. The most baffling problems involving, for example, botulism in cattle arising indirectly from deficiency conditions found solution through his efforts. Although he had to deal with problems of great practical importance, his interests were in fundamental scientific principles. It is probably widely recognized that his great success is attributable to his interest in research in combination with unusual administrative capacity and an ability to obtain adequate support for the work in which he was engaged. From 1920 to 1927 he served as Director of Veterinary Education and Research for the Union of South Africa and Professor of Tropical Veterinary Medicine at the Transvaal University and became Dean of the Faculty of Veterinary Science at the University of South Africa, retiring in 1927. His work did not cease with retirement, for this made available time for researches to which he devoted the remainder of his life. One of the outstanding qualities of Sir Arnold's character was the impelling force without which the unusual quantity and quality of his contributions would have been impossible. He spared neither himself nor his staff when there was work to do. His visits to Boston are recalled for the stimulation they contributed to a wide group of interests.

It falls to the lot of very few individuals to receive the number of honors justly bestowed on Sir Arnold. It may be truly said that while he was afforded unusual opportunities, these he utilized to an extent that few could attain.

E. E. Tyzzer

STATUTES AND STANDING VOTES

The Statutes and Standing Votes of the Academy are in the process of revision. It is not, therefore, feasible to print them at this time.

RUMFORD PREMIUM

In conformity with the terms of the gift of Sir Benjamin Thompson, Count Rumford, of a certain Fund to the American Academy of Arts and Sciences, and with a decree of the Supreme Judicial Court of Massachusetts for carrying into effect the general charitable intent and purpose of Count Rumford, as expressed in his letter of gift, the Academy is empowered to make from the income of the Rumford Fund, as it now exists, at any Annual Meeting, an award of a gold and a silver medal, being together of the intrinsic value of three hundred dollars, as a Premium to the author of any important discovery or useful inprovement in light or heat, which shall have been made and published by printing, or in any way made known to the public, in any part of the continent of America, or any of the American islands; preference always being given to such discoveries as, in the opinion of the Academy, shall tend most to promote the good of mankind; and, if the Academy sees fit, to add to such medals, as a further Premium for such discovery and improvement, a sum of money not exceeding three hundred dollars.

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American Academy of Arts and Sciences.

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The Recording Secretary,

James R. Jack,
Tenney L. Davis,
Abbott P. Usher,
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FELLOWS AND FOREIGN HONORARY MEMBERS

(Corrected to February 14, 1939)

FELLOWS—773

(Number limited to eight hundred)

The year of election is indicated in the left margin, the century being omitted; thus 21 means 1921, 92 means 1892. When a Fellow resigned and was re-elected, the year of re-election is indicated in the ordinary way, the year of election is enclosed in square brackets. The year of election of an Associate, now a Fellow, is indicated by round brackets.

CLASS I—Mathematical and Physical Sciences—208

Section I—*Mathematics and Astronomy*—49

21	Charles Greeley Abbot	Washington, D. C.
32	Clarence Raymond Adams	Providence, R. I.
22	Walter Sydney Adams	Pasadena, Cal.
12	George Russell Agassiz	Boston
17	Raymond Clare Archibald	Providence, R. I.
32	Albert Arnold Bennett	Providence, R. I.
13	George David Birkhoff	Cambridge
35	Gilbert Ames Bliss	Chicago, Ill.
13	Julian Lowell Coolidge	Cambridge
15	Leonard Eugene Dickson	Chicago, Ill.
33	Jesse Douglas	Brooklyn, N. Y.
38	John Charles Duncan	Wellesley
34	Griffith Conrad Evans	Berkeley, Cal.
15	Philip Fox	Evanston, Ill.
30	Philip Franklin	Belmont
24	William Caspar Graustein	Cambridge
32	Einar Hille	New Haven, Conn.
15	Frank Lauren Hitchcock	Belmont
13	Edward Vermilye Huntington	Cambridge
15	Dunham Jackson	Minneapolis, Minn.
38	E[lvin] Morton Jellinek	Worcester
15	Carl Otto Lampland	Flagstaff, Ariz.
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24	John Anthony Miller	Wallingford, Pa.
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18	Henry Bayard Phillips	Belmont
96	Charles Lane Poor	New York, N. Y.
14	Roland George Dwight Richardson	Providence, R. I.
21	Henry Norris Russell	Princeton, N. J.
31	George Rutledge	Belmont
21	Frank Schlesinger	New Haven, Conn.
20	Harlow Shapley	Cambridge
09	Vesto Melvin Slipher	Flagstaff, Ariz.
17	Frederick Slocum	Middletown, Conn.
19	Virgil Snyder	Ithaca, N. Y.
21	Joel Stebbins	Madison, Wis.
27	Harlan True Stetson	Waban
33	Marshall Harvey Stone	Cambridge
30	Dirk Jan Struik	Belmont
28	Jacob David Tamarkin	Providence, R. I.
23	Oswald Veblen	Princeton, N. J.
29	Joseph Leonard Walsh	Cambridge
25	Alfred North Whitehead	Cambridge
32	David Vernon Widder	Cambridge
12	Frederick Shenstone Woods	Newton Center

Class I, Section II—*Physics*—60

28	Adelbert Ames, Jr.	Hanover, N. H.
11	Joseph Sweetman Ames	Baltimore, Md.
37	Kenneth Tompkins Bainbridge	Cambridge
21	Samuel Jackson Barnett	Los Angeles, Cal.
12	Percy William Bridgman	Cambridge
26	Walter Guyton Cady	Middletown, Conn.
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21	Leslie Lyle Campbell	Lexington, Va.
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34	Franzo Hazlett Crawford	Williamstown
13	Henry Crew	Evanston, Ill.
11	Harvey Nathaniel Davis	Hoboken, N. J.
29	Clinton Joseph Davisson	New York, N. Y.
12	Arthur Louis Day	Bethesda, Md.
14	William Johnson Drisko	Addison, Me.

01 Alexander Wilmer Duff . . . . Worcester
09 Arthur Woolsey Ewell . . . . Worcester
97 Harry Manley Goodwin . . . . Brookline
29 Arthur Cobb Hardy . . . . Wellesley
31 George Russell Harrison . . . . Belmont
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14 John Charles Hubbard . . . . Baltimore, Md.
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14 Charles Clifford Hutchins . . . . Brunswick, Me.
14 James Edmund Ives . . . . Washington, D. C.
22 Edwin Crawford Kemble . . . . Cambridge
13 Norton Adams Kent . . . . Newton Center
37 Ernest Orlando Lawrence . . . . Berkeley, Cal.
99 Henry Lefavour . . . . Boston
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14 Dayton Clarence Miller . . . . Cleveland, O.
14 Robert Andrews Millikan . . . . Pasadena, Cal.
34 Harry Rowe Mimno . . . . Cambridge
34 Philip McCord Morse . . . . Belmont
07 Charles Ladd Norton . . . . Boston
31 Otto Oldenberg . . . . Cambridge
34 Leigh Page . . . . New Haven, Conn.
07 George Washington Pierce . . . . Cambridge
35 Floyd Karker Richtmyer . . . . Ithaca, N. Y.
16 Frederick Albert Saunders . . . . Cambridge
27 John Clarke Slater . . . . Cambridge
37 George William Stewart . . . . Iowa City, Ia.
96 John Stone Stone . . . . San Diego, Cal.
37 Jabez Curry Street . . . . Cambridge
12 Maurice deKay Thompson . . . . Brookline
28 Manuel Sandoval Vallarta . . . . Brookline
35 Robert Jemison Van de Graaff . . . . Cambridge
34 John Hasbrouck Van Vleck . . . . Cambridge
35 Bertram Eugene Warren . . . . Cambridge
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11 Edwin Bidwell Wilson . . . . Brookline
13 Robert Williams Wood . . . . Baltimore, Md.
17 John Zeleny . . . . New Haven, Conn.

CLASS I, SECTION III—*Chemistry*—53

26 Roger Adams . . . . Urbana, Ill.
13 Wilder Dwight Bancroft . . . . Ithaca, N. Y.
07 Gregory Paul Baxter . . . . Cambridge
29 James Alexander Beattie . . . . Belmont
19 Arthur Alphonzo Blanchard . . . . Brookline
14 Marston Taylor Bogert . . . . New York, N. Y.
36 Harold Simmons Booth . . . . Cleveland, O.
11 William Crowell Bray . . . . Berkeley, Cal.
38 Emile Monnin Chamot . . . . Ithaca, N. Y.
12 Russell Henry Chittenden . . . . . New Haven, Conn.
24 James Bryant Conant . . . . Cambridge
23 Tenney Lombard Davis . . . . Norwell
37 John Tileston Edsall . . . . Cambridge
37 Gustavus John Esselen . . . . Swampscott
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33 Louis Frederick Fieser . . . . Waltham
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36 Albert Baird Hastings . . . . Cambridge
12 Lawrence Joseph Henderson . . . . Cambridge
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36 Ernest Hamlin Huntress . . . . Melrose Highlands
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19 Frederick George Keyes . . . . Cambridge
33 George Bogdan Kistiakowsky . . . . Cambridge
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09 Gilbert Newton Lewis . . . . Berkeley, Cal.
15 Warren Kendall Lewis . . . . Newton
23 Duncan Arthur MacInnes . . . . New York, N. Y.
32 Kenneth Lamartine Mark . . . . Boston
35 Nicholas Athanasius Milas . . . . Belmont
36 Avery Adrian Morton . . . . Watertown
19 Edward Mueller . . . . Cambridge
07 James Flack Norris . . . . Boston
13 William Albert Noyes . . . . Urbana, Ill.
31 William Albert Noyes, Jr. . . . . Rochester, N. Y.
14 Samuel Cate Prescott . . . . Brookline
79 Robert Hallowell Richards . . . . Jamaica Plain
14 Martin André Rosanoff . . . . Pittsburgh, Pa.
28 George Scatchard . . . . Cambridge
32 Walter Cecil Schumb . . . . East Milton
15 Miles Standish Sherrill . . . . Brookline
20 Harry Monmouth Smith . . . . Brookline
34 Leighton Bruerton Smith . . . . Beverly
22 Richard Chace Tolman . . . . Pasadena, Cal.
38 Harold Clayton Urey . . . . Leonia, N. J.
11 Willis Rodney Whitney . . . . Schenectady, N. Y.
19 Robert Seaton Williams . . . . Belmont
34 David Elbridge Worrall . . . . Medford

CLASS I, SECTION IV—*Technology and Engineering*—46

06 Comfort Avery Adams . . . . Philadelphia, Pa.
33 Harold Kilbrith Barrows . . . . Winchester
31 Charles Harold Berry . . . . Belmont
25 Vannevar Bush . . . . Washington, D. C.
34 Otto Gustav Colbiornsen Dahl . . . . Brookline
34 Chester Laurens Dawes . . . . Cambridge
38 Alfred Victor de Forest . . . . Cambridge
34 Jacob Pieter Den Hartog . . . . Wellesley Hills
20 Theodore Harwood Dillon . . . . Brookline
27 Philip Drinker . . . . Newton Center
22 Gano Dunn . . . . New York, N. Y.
21 William Frederick Durand . . . . Palo Alto, Cal.
27 Gordon Maskew Fair . . . . Cambridge
19 Frederic Harold Fay . . . . Boston
32 Glennon Gilboy . . . . Lincoln
32 Albert Haertlein . . . . Watertown
36 Murray Philip Horwood . . . . Newton Center
23 William Hovgaard . . . . Brooklyn, N. Y.
34 Jerome Clarke Hunsaker . . . . Boston
23 James Robertson Jack . . . . Watertown

11 Dugald Caleb Jackson................Cambridge
30 Frank Baldwin Jewett..........New York, N. Y.
01 Lewis Jerome Johnson...............Cambridge
37 Joseph Henry Keenan..................Belmont
05 Arthur Edwin Kennelly..............Cambridge
32 Ralph Restieaux Lawrence.............Belmont
23 William Henry Lawrence...........Jamaica Plain
38 John Moyes Lessells..................Brookline
21 Charles Thomas Main................Winchester
12 Lionel Simeon Marks................Cambridge
34 Edward Leyburn Moreland.............Wellesley
33 Arthur Edwin Norton................Cambridge
20 Frederick Law Olmsted...............Brookline
15 Charles Francis Park..................Taunton
28 Langdon Pearse...................Chicago, Ill.
13 Harold Pender.................Philadelphia, Pa.
30 Greenleaf Whittier Pickard........Newton Center
30 George Edmond Russell.................Bedford
01 Henry Lloyd Smyth................Windsor, Vt.
14 Charles Milton Spofford.................Boston
28 John F. Stevens.................Baltimore, Md.
23 Edward Pearson Warner........New York, N. Y.
29 Arthur Edward Wells...........New York, N. Y.
37 Harald Malcolm Westergaard...........Belmont
27 Robert Spurr Weston..................Brookline
15 Joseph Ruggles Worcester..............Waltham

CLASS II—Natural and Physiological Sciences—211

Section I—*Geology, Mineralogy, and Physics of the Globe*—51

15 Wallace Walter Atwood..............Worcester
38 Marland Pratt Billings...................Boston
21 Norman Levi Bowen................Chicago, Ill.
16 Isaiah Bowman.................Baltimore, Md.
33 Charles Franklin Brooks..................Milton
29 Kirk Bryan........................Cambridge
33 Frank Morton Carpenter.............Newtonville
93 Henry Helm Clayton...................Canton
09 Reginald Aldworth Daly..............Cambridge
34 Sterling Price Fergusson..................Milton
18 William Ebenezer Ford........New Haven, Conn.
17 James Walter Goldthwait.........Hanover, N. H.
14 Louis Caryl Graton..................Cambridge
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16 Ellsworth Huntington.........New Haven, Conn.
95 Robert Tracy Jackson...................Boston
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08 Douglas Wilson Johnson........New York, N. Y.
21 Arthur Keith................Washington, D. C.
10 Alfred Church Lane.................Cambridge
25 Esper Signius Larson, Jr................Belmont
15 Andrew Cowper Lawson...........Berkeley, Cal.
16 Charles Kenneth Leith............Madison, Wis.
12 Waldemar Lindgren..................Brookline
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31 George Francis McEwen............La Jolla, Cal.
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25 Kirtley Fletcher Mather..........Newton Center
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17 William John Miller............Los Angeles, Cal.
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34 Walter Harry Newhouse...............Medford
03 Charles Palache.....................Cambridge
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15 Charles Schuchert............New Haven, Conn.
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11 Hervey Woodburn Shimer.............Hingham
17 Thomas Wayland Vaughan.....Washington, D. C.
08 Charles Hyde Warren.........New Haven, Conn.
14 Herbert Percy Whitlock.........New York, N. Y.
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15 Bailey Willis......................Palo Alto, Cal.
95 John Eliot Wolff.................Pasadena, Cal.
15 Frederick Eugene Wright......Washington, D. C.

Class II, Section II—*Botany*—35

30 LeRoy Abrams..........Stanford University, Cal.
11 Oakes Ames.....................North Easton
34 Edgar Anderson.................St. Louis, Mo.
23 Joseph Charles Arthur............Lafayette, Ind.
15 Irving Widmer Bailey...............Cambridge
00 Liberty Hyde Bailey...............Ithaca, N. Y.
21 Edward Wilber Berry...........Baltimore, Md.
98 Douglas Houghton Campbell.......Palo Alto, Cal.
16 Bradley Moore Davis..........Ann Arbor, Mich.
35 Bernard Ogilvie Dodge..........New York, N. Y.
21 Rollins Adams Emerson............Ithaca, N. Y.
12 Alexander William Evans......New Haven, Conn.
29 Joseph Horace Faull.................Cambridge
00 Merritt Lyndon Fernald.............Cambridge
11 Robert Almer Harper...........New York, N. Y.
98 John George Jack.................East Walpole
28 Willis Linn Jepson................Berkeley, Cal.
27 Ivan Murray Johnston................Brookline
34 Donald Forsha Jones..........New Haven, Conn.
21 Jacob Goodale Lipman.....New Brunswick, N. J.
14 Burton Edward Livingston........Baltimore, Md.
21 Elmer Drew Merrill...............Jamaica Plain
10 Winthrop John Vanleuven Osterhout New York, N. Y.
27 George James Peirce..............Palo Alto, Cal.
14 Alfred Rehder....................Jamaica Plain
30 Karl Sax.........................Jamaica Plain
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34 Edmund Ware Sinnott..........New York, N. Y.
34 Gilbert Morgan Smith....Stanford University, Cal.
23 Elvin Charles Stakman...........St. Paul, Minn.
38 Kenneth Vivian Thimann.............Cambridge
92 William Trelease....................Urbana, Ill.
31 Charles Alfred Weatherby............Cambridge

22 William Henry Weston, Jr.	Cambridge
32 Ralph Hartley Wetmore	Belmont

CLASS II, SECTION III—*Zoology and Physiology*—71

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16 Thomas Barbour	Boston
33 Philip Bard	Baltimore, Md.
09 Francis Gano Benedict	Machiasport, Me.
11 Henry Bryant Bigelow	Concord
14 Robert Payne Bigelow	Brookline
35 Charles Henry Blake	Lincoln
20 William T. Bovie	Waterville, Me.
24 Edward Allen Boyden	Minneapolis, Minn.
16 John Lewis Bremer	Boston
15 Charles Thomas Brues	Jamaica Plain
28 John Wymond Miller Bunker	Belmont
06 Walter Bradford Cannon	Cambridge
22 Thorne Martin Carpenter	Boston
00 William Ernest Castle	Berkeley, Cal.
14 Charles Value Chapin	Providence, R. I.
29 Lemuel Roscoe Cleveland	Jamaica Plain
26 Edwin Joseph Cohn	Cambridge
14 Edwin Grant Conklin	Princeton, N. J.
23 Manton Copeland	Brunswick, Me.
27 William John Crozier	Cambridge
17 Joseph Augustine Cushman	Sharon
35 J[ohn] Frank[lin] Daniel	Berkeley, Cal.
95 Charles Benedict Davenport	Cold Spring Harbor
29 Hallowell Davis	Belmont
33 Alden Benjamin Dawson	Belmont
25 Samuel Randall Detwiler	New York, N. Y.
25 Herbert McLean Evans	Berkeley, Cal.
30 Henry Clinton Fall	Tyngsboro
34 Cyrus Hartwell Fiske	Belmont
15 Alexander Forbes	Milton
34 John Farquhar Fulton	New Haven, Conn.
31 William King Gregory	New York, N. Y.
29 Joseph Grinnell	Berkeley, Cal.
89 Samuel Henshaw	Cambridge
36 Frederick Lee Hisaw	Cambridge
29 Leigh Hoadley	Cambridge
34 Hudson Hoagland	Worcester
24 Samuel Jackson Holmes	Berkeley, Cal.
28 Roy Graham Hoskins	Waban
13 Leland Ossian Howard	Washington, D. C.
14 Herbert Spencer Jennings	Baltimore, Md.
13 Charles Atwood Kofoid	Berkeley, Cal.
16 Frederic Thomas Lewis	Waban
33 Frank Rattray Lillie	Chicago, Ill.
14 Ralph Stayner Lillie	Chicago, Ill.
17 Richard Swann Lull	New Haven, Conn.
84 Edward Laurens Mark	Cambridge
15 Albert Davis Mead	Providence, R. I.
27 Axel Leonard Melander	New York, N. Y.
35 Karl Friedrich Meyer	San Francisco, Cal.
21 Gerrit Smith Miller	Washington, D. C.
28 Thomas Hunt Morgan	Pasadena, Cal.
14 Herbert Vincent Neal	Salisbury Cove, Me.
95 George Howard Parker	Cambridge
19 Raymond Pearl	Baltimore, Md.
21 Henry Augustus Pilsbry	Philadelphia, Pa.
27 Frederick Haven Pratt	Wellesley Hills
09 Herbert Wilbur Rand	Belmont
32 David Rapport	Cambridge
23 Alfred Clarence Redfield	Milton
34 Alfred Newton Richards	Philadelphia, Pa.
34 Oscar Riddle	Cold Spring Harbor, N. Y.
13 William Emerson Ritter	Berkeley, Cal.
37 Alfred Sherwood Romer	Cambridge
25 Alexander Grant Ruthven	Ann Arbor, Mich.
15 Arthur Wisswald Weysse	Boston
02 Edmund Beecher Wilson	New York, N. Y.
38 George Bernays Wislocki	Milton
15 Frederick Adams Woods	Rome, Italy
33 Jeffries Wyman, Jr.	Chestnut Hill

CLASS II, SECTION IV—*Medicine and Surgery*—54

32 Joseph Charles Aub	Belmont
36 Oswald Theodore Avery	New York, N. Y.
29 James Bourne Ayer	Milton
(28) 32 Franklin Greene Balch	Boston
31 George Blumer	New Haven, Conn.
36 Charles Sidney Burwell	Brookline
21 Charles Macfie Campbell	Cambridge
19 Alexis Carrel	New York, N. Y.
31 William Bosworth Castle	Brookline
30 David Cheever	Boston
13 Henry Asbury Christian	Brookline
21 Rufus Cole	Mount Kisco, N. Y.
14 Harvey Cushing	New Haven, Conn.
32 Elliott Carr Cutler	Brookline
31 Eugene Floyd DuBois	New York, N. Y.
33 Reginald Fitz	Brookline
11 Simon Flexner	New York, N. Y.
27 James Lawder Gamble	Brookline
22 Joseph Lincoln Goodale	Ipswich
21 Ross Granville Harrison	New Haven, Conn.
27 Percy Rogers Howe	Belmont
21 William Henry Howell	Baltimore, Md.
33 Edgar Erskine Hume	Carlisle, Pa.
15 Reid Hunt	Boston
34 Henry Jackson, Jr.	Chestnut Hill
12 Elliott Proctor Joslin	Boston
23 Roger Irving Lee	Brookline
29 Edwin Allen Locke	Williamstown
28 Warfield Theobald Longcope	Baltimore, Md.
32 Fred Bates Lund	Newton
13 Frank Burr Mallory	Brookline
21 William James Mayo	Rochester, Minn.
34 Leroy Matthew Simpson Miner	Newtonville
26 George Richards Minot	Brookline
28 William Lorenzo Moss	Athens, Ga.
28 John Howard Mueller	West Roxbury
25 Robert Bayley Osgood	Boston
37 Walter Walker Palmer	New York, N. Y.
27 Joseph Hershey Pratt	Boston
35 Tracy Jackson Putnam	Brookline
34 William Carter Quinby	Brookline

34 Arthur Hiler Ruggles	Providence, R. I.
27 Andrew Watson Sellards	Boston
33 George Cheever Shattuck	Brookline
30 Torald Hermann Sollmann	Cleveland, Ohio
21 Charles Wardell Stiles	Washington, D. C.
14 Richard Pearson Strong	Boston
30 Fritz Bradley Talbot	Brookline
14 Ernest Edward Tyzzer	Wakefield
14 Frederick Herman Verhoeff	Brookline
27 Joseph Treloar Wearn	Cleveland, Ohio
33 Soma Weiss	Cambridge
12 Simeon Burt Wolbach	South Sudbury
23 Hans Zinsser	Boston

CLASS III—THE SOCIAL ARTS—154

SECTION I—*Jurisprudence*—41

(24) 32 Francis Noyes Balch	Jamaica Plain
38 Henry Moore Bates	Ann Arbor, Mich.
06 Joseph Henry Beale	Cambridge
36 Stoughton Bell	Cambridge
33 Harry Augustus Bigelow	Chicago, Ill.
33 Henry Wolf Biklé	Philadelphia, Pa.
36 Wilfred Bolster	Brookline
36 Claude Raymond Branch	Providence, R. I.
33 John Dickinson	Washington, D. C.
38 Robert Gray Dodge	Boston
31 Fred Tarbell Field	Newton
32 Felix Frankfurter	Washington, D. C.
30 Thomas Hovey Gage	Worcester
33 Theodore Francis Green	Providence, R. I.
38 Frank Washburn Grinnell	Boston
33 Learned Hand	New York, N. Y.
18 Charles Evans Hughes	Washington, D. C.
31 Nathan Isaacs	Cambridge
38 Melvin Maynard Johnson	Brookline
38 James McCauley Landis	Cambridge
21 Frederick Lawton	Boston
32 Sayre Macneil	Azusa, Cal.
32 Calvert Magruder	Cambridge
31 William DeWitt Mitchell	New York, N. Y.
31 Edmund Morris Morgan	Arlington
38 James Madison Morton, Jr.	Fall River
36 Philip Stanley Parker	Brookline
36 Henry Parkman, Jr.	Boston
01 George Wharton Pepper	Philadelphia, Pa.
11 Roscoe Pound	Watertown
38 William Morton Prest	Boston
36 Stanley Elroy Qua	Lowell
32 Francis Bowes Sayre	Washington, D. C.
21 Austin Wakeman Scott	Cambridge
35 James Brown Scott	Washington, D. C.
36 Sidney Post Simpson	Cambridge
33 Harlan Fiske Stone	Washington, D. C.
32 Edward Sampson Thurston	Cambridge
14 Eugene Wambaugh	Cambridge
38 Bentley Wirt Warren	Boston
37 Joseph Warren	Brookline
(28) 32 Edmund Allen Whitman	Cambridge

CLASS III, SECTION II—*Government, International Law, and Diplomacy*—24

36 Howard Landis Bevis	Cambridge
33 Edwin Montefiore Borchard	New Haven, Conn.
32 William Richards Castle, Jr.	Washington, D. C.
32 Joseph Perkins Chamberlain	New York, N. Y.
33 Robert Treat Crane	New York, N. Y.
35 Tyler Dennett	Hague, N. Y.
31 Sidney Bradshaw Fay	Cambridge
27 William Cameron Forbes	Norwood
34 Edgar Stephenson Furniss	New Haven, Conn.
32 Joseph Clark Grew	Tokyo, Japan
35 Charles Grove Haines	Los Angeles, Cal.
16 Albert Bushnell Hart	Cambridge
27 Arthur Norman Holcombe	Cambridge
31 Manley Ottmer Hudson	Cambridge
32 Philip Carryl Jessup	New York, N. Y.
97 Abbott Lawrence Lowell	Boston
32 Charles Edward Merriam	Chicago, Ill.
19 John Bassett Moore	New York, N. Y.
13 William Bennett Munro	Pasadena, Cal.
27 Westel Woodbury Willoughby	Washington, D. C.
32 William Franklin Willoughby	Washington, D. C.
14 George Grafton Wilson	Cambridge
27 Quincy Wright	Chicago, Ill.
33 Henry Aaron Yeomans	Cambridge

CLASS III, SECTION III—*Economics and Sociology*—62

36 James Waterhouse Angell	New York, N. Y.
36 James Cummings Bonbright	New York, N. Y.
33 Harold Hitchings Burbank	Cambridge
36 Philip Cabot	Milton
36 Edward Hastings Chamberlin	Cambridge
34 John Maurice Clark	Westport, Conn.
28 Arthur Harrison Cole	Cambridge
31 Melvin Thomas Copeland	Cambridge
31 William Leonard Crum	Cambridge
32 William James Cunningham	Cambridge
34 Winthrop More Daniels	Saybrook Point, Conn.
21 Clive Day	New Haven, Conn.
13 Davis Rich Dewey	Cambridge
32 Arthur Stone Dewing	Newton
32 Wallace Brett Donham	Boston
34 John Franklin Ebersole	Belmont
36 Fred Rogers Fairchild	New Haven, Conn.
36 Frank Albert Fetter	Princeton, N. J.
12 Irving Fisher	New Haven, Conn.
31 James Ford	Cambridge
34 Ralph Evans Freeman	Cambridge
13 Edwin Francis Gay	Pasadena, Cal.
33 Sheldon Glueck	Cambridge
34 Robert Murray Haig	New York, N. Y.
32 Henry Wyman Holmes	Cambridge
34 Edwin Walter Kemmerer	Princeton, N. J.
34 Frank Hyneman Knight	Chicago, Ill.
36 Roswell Cheney McCrea	New York, N. Y.
34 Robert Morison MacIver	New York, N. Y.
32 Walter Wallace McLaren	Williamstown

36 Malcolm Perrine McNair.............Cambridge
32 Leon Carroll Marshall.........Chevy Chase, Md.
33 Edward Sagendorph Mason...........Cambridge
36 Elton Mayo..........................Cambridge
34 Richard Stockton Meriam..........South Lincoln
34 Harry Alvin Millis..................Chicago, Ill.
32 Frederick Cecil Mills...........New York, N. Y.
31 Wesley Clair Mitchell...........New York, N. Y.
34 Arthur Eli Monroe..................Cambridge
32 Harold Glenn Moulton........ Washington, D. C.
34 Edwin Griswold Nourse........Washington, D. C.
32 William Fielding Ogburn.............Chicago, Ill.
33 Robert Ezra Park..................Chicago, Ill.
32 Leo S. Rowe................Washington, D. C.
37 Clyde Orval Ruggles................Cambridge
36 Thomas Henry Sanders..............Cambridge
33 Josef Alois Schumpeter..............Cambridge
32 Carl Snyder..................New York, N. Y.
31 Pitirim Alexandrovich Sorokin.........Winchester
31 Oliver Mitchell Wentworth Sprague....Cambridge
[89] 01 Frank William Taussig...........Cambridge
34 Frederick John Teggart............Berkeley, Cal.
33 William Isaac Thomas..........New York, N. Y.
37 Harry Rudolph Tosdal..................Belmont
31 Donald Skeele Tucker..................Belmont
33 Abbott Payson Usher................Cambridge
34 Jacob Viner.......................Chicago, Ill.
38 T[homas] North Whitehead...........Cambridge
32 John Henry Williams................Cambridge
36 Joseph Henry Willits...........Swarthmore, Pa.
34 Leo Wolman..................New York, N. Y.
34 Carle Clark Zimmerman.............Winchester

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(25) 32 Charles Francis Adams............Concord
(25) 32 Charles Foster Batchelder.........Cambridge
38 Edmund Ezra Day................Ithaca, N. Y.
32 Henry Sturgis Dennison.............Framingham
(28) 32 William Lusk Webster Field..........Milton
38 Horace Sayford Ford..................Belmont
16 Frank Johnson Goodnow..........Baltimore, Md.
35 Jerome Davis Greene................Cambridge
(28) 32 Edward Jackson Holmes.............Boston
34 Matt Bushnell Jones.............Newton Center
34 Henry Plimpton Kendall................Walpole
(27) 32 Nathaniel Thayer Kidder............Milton
32 Thomas William Lamont........New York, N. Y.
34 Clarence Cook Little...........Bar Harbor, Me.
36 Dumas Malone.....................Cambridge
33 James Vance May.......................Boston
02 Herbert Putnam.............Washington, D. C.
(28) 32 Alfred Lawrence Ripley............Andover
34 Erwin Haskell Schell................Cambridge
38 Charles Seymour............New Haven, Conn.
35 Henry Lee Shattuck.....................Boston
37 Henry Southworth Shaw...........Exeter, N. H.
(28) 32 Payson Smith...................Brookline
33 Albert Warren Stearns.................Billerica
(25) 32 Charles Henry Taylor..............Boston
36 Clair Elsmere Turner..................Arlington
(24) 32 Edwin Sibley Webster............Brookline
(25) 32 Benjamin Loring Young............Weston

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32 Michael Joseph Ahern..................Weston
33 Gordon Willard Allport...............Cambridge
32 James Rowland Angell........New Haven, Conn.
33 John Gilbert Beebe-Center...........Swampscott
38 Julius Seelye Bixler..................Cambridge
24 Edwin Garrigues Boring..............Cambridge
28 Edgar Sheffield Brightman...............Newton
31 Henry Addington Bruce..............Cambridge
32 Leonard Carmichael...............Tufts College
36 Robert Pierce Casey............Providence, R. I.
33 J[ames] McKeen Cattell..........Garrison, N. Y.
28 Walter Fenno Dearborn...............Cambridge
18 Edmund Burke Delabarre.......Providence, R. I.
24 Raymond Dodge.................Tryon, N. C.
33 Curt John Ducasse.............Providence, R. I.
38 James Everett Frame............Princeton, N. J.
37 Clarence Henry Graham........Providence, R. I.
30 William Henry Paine Hatch...........Cambridge
32 William Healy.........................Boston
10 William Arthur Heidel........Middletown, Conn.
21 William Ernest Hocking.............Cambridge
35 Clark Leonard Hull...........New Haven, Conn.
33 Walter Samuel Hunter..........Providence, R. I.
17 Frederick John Foakes Jackson...Englewood, N. J.
28 Albert Cornelius Knudson............Cambridge
34 Kurt Koffka.....................Northampton
32 Karl Spencer Lashley..................Belmont
13 William Lawrence......................Boston
29 Clarence Irving Lewis.................Lexington
33 Lee Sullivan McCollester...........Tufts College
10 Edward Caldwell Moore.............Cambridge
35 Henry Alexander Murray, Jr..............Boston
32 Arthur Darby Nock...................Cambridge
32 William Cardinal O'Connell..............Boston
28 Johnson O'Connor......................Boston
17 Charles Edwards Park..................Boston
33 Carroll Cornelius Pratt.....New Brunswick, N. J.
30 James Hugh Ryan................Omaha, Neb.
31 Henry Knox Sherrill......................Boston
27 Willard Learoyd Sperry...............Cambridge
29 Russell Henry Stafford................Brookline
34 Lewis Madison Terman...Stanford University, Cal.
34 Edward Lee Thorndike.........New York, N. Y.
37 Louis Leon Thurstone..............Chicago, Ill.
28 Henry Bradford Washburn............Cambridge
17 John Broadus Watson..........New York, N. Y.
33 Frederic Lyman Wells.........Newton Highlands
35 Robert Sessions Woodworth.....New York, N. Y.
15 Robert Mearns Yerkes.......New Haven, Conn.

Class IV, Section II—*History, Archaeology, and Anthropology*—40

18 Charles McClean Andrews.....New Haven, Conn.
28 James Phinney Baxter, 3d..........Williamstown
23 Carl Lotus Becker..................Ithaca, N. Y.
27 Robert Pierpont Blake................Cambridge
12 Franz Boas....................New York, N. Y.
(25) 32 William Brooks Cabot...............Boston
34 Clarence Gordon Campbell......New York, N. Y.
12 George Henry Chase..................Cambridge
21 Max Farrand...................San Marino, Cal.
21 William Scott Ferguson..............Cambridge
38 Allyn Bailey Forbes..................Cambridge
10 Worthington Chauncey Ford..........Cambridge
33 Henry Thatcher Fowler.........Providence, R. I.
38 Claude Moore Fuess...................Andover
18 Evarts Boutell Greene..........New York, N. Y.
19 Charles Downer Hazen..........New York, N. Y.
14 Bert Hodge Hill...................Athens, Greece
27 Earnest Albert Hooton..............Cambridge
33 Halford Lancaster Hoskins..........Tufts College
15 Aleš Hrdlička.................Washington, D. C.
12 Alfred Louis Kroeber..............Berkeley, Cal.
15 Kirsopp Lake....................Haverford, Pa.
22 George LaPiana.......................Cambridge
32 Waldo Gifford Leland.........Washington, D. C.
20 Charles Howard McIlwain..............Belmont
14 Roger Bigelow Merriman.............Cambridge
38 Stewart Mitchell.........................Boston
15 Samuel Eliot Morison...................Boston
34 Robert Henry Pfeiffer................Cambridge
14 George Andrew Reisner..................Boston
34 David Moore Robinson...........Baltimore, Md.
23 Michael Ivanovich Rostovtzeff.New Haven, Conn.
27 George Sarton.........................Cambridge
38 Bernadotte Everly Schmitt..........Chicago, Ill.
36 Donald Scott..........................Cambridge
34 Theodore Leslie Shear...........Princeton, N. J.
26 Herbert Joseph Spinden..........Brooklyn, N. Y.
32 Charles Holt Taylor..................Cambridge
11 Alfred Marston Tozzer................Cambridge
20 Clark Wissler...................New York, N. Y.

Class IV, Section III—*Philology*—60

31 Edward Cooke Armstrong........Princeton, N. J.
33 William Nickerson Bates........Philadelphia, Pa.
35 Charles Henry Beeson...............Chicago, Ill.
33 Campbell Bonner...............Ann Arbor, Mich.
35 Robert Johnson Bonner..............Chicago, Ill.
33 Carleton Brown.................New York, N. Y.
21 Carl Darling Buck...................Chicago, Ill.
18 Edward Capps...................Princeton, N. J.
20 Walter Eugene Clark..................Cambridge
32 Ronald Salmon Crane...............Chicago, Ill.
38 James Pyle Wickersham Crawford Philadelphia, Pa.
32 Morris William Croll............Princeton, N. J.
31 Samuel Hazzard Cross................Cambridge
20 Franklin Edgerton............New Haven, Conn.
21 Frank Edgar Farley..........Middletown, Conn.
14 Jeremiah Denis Mathias Ford.........Cambridge
35 Tenney Frank...................Baltimore, Md.
30 James Geddes, Jr.....................Brookline
13 Charles Hall Grandgent...............Cambridge
16 Louis Herbert Gray............New York, N. Y.
25 William Chase Greene................Cambridge
13 Charles Burton Gulick................Cambridge
19 Roy Kenneth Hack.............Cincinnati, Ohio
34 Austin Morris Harmon........New Haven, Conn.
31 Raymond Dexter Havens.........Baltimore, Md.
38 Richmond Laurin Hawkins............Cambridge
18 George Lincoln Hendrickson....New Haven, Conn.
17 William Guild Howard................Cambridge
21 Eugene Xavier Louis Henry Hyvernat, Wash., D. C.
15 Carl Newell Jackson..................Cambridge
13 James Richard Jewett................Cambridge
32 (Ralph) Hayward Keniston..........Chicago, Ill.
34 Roland Grubb Kent.............Philadelphia, Pa.
98 George Lyman Kittredge..............Cambridge
33 Hans Kurath...................Providence, R. I.
32 Ernest Felix Langley.................Cambridge
[81] 98 Charles Rockwell Lanman.........Cambridge
33 Ivan Mortimer Linforth............Berkeley, Cal.
11 Albert Matthews.........................Boston
35 Benjamin Dean Meritt...........Princeton, N. J.
28 William Albert Nitze...............Chicago, Ill.
32 George Rapall Noyes..............Berkeley, Cal.
34 William Abbott Oldfather............Urbana, Ill.
33 Howard Rollin Patch...............Northampton
32 Arthur Stanley Pease.................Cambridge
35 Henry Washington Prescott..........Chicago, Ill.
13 Edward Kennard Rand...............Cambridge
11 Fred Norris Robinson................Cambridge
38 Hyder Edward Rollins................Cambridge
31 Robert Kilburn Root............Princeton, N. J.
35 Henry Arthur Sanders..........Ann Arbor, Mich.
18 Rudolph Schevill..................Berkeley, Cal.
32 Horatio Elwin Smith............New York, N. Y.
89 Franklin Bache Stephenson.....Washington, D. C.
32 William Thomson....................Cambridge
11 Charles Cutler Torrey.........New Haven, Conn.
33 George Benson Weston................Cambridge
30 Ernest Hatch Wilkins..............Oberlin, Ohio
33 Harry Austryn Wolfson...............Cambridge
33 Karl Young.....................New Haven, Conn.

Class IV, Section IV—*The Fine Arts and Belles Lettres*—51

31 Stephen Vincent Benét..........New York, N. Y.
26 Frank Weston Benson.....................Salem
32 (William) Welles Bosworth......New York, N. Y.
33 John Alden Carpenter................Chicago, Ill.
32 Chalmers Dancy Clifton..........Westport, Conn.
33 Charles Collens...................Newton Center
32 Kenneth John Conant................Cambridge
34 Charles Jay Connick................Newtonville
29 Charles Townsend Copeland...........Cambridge

[17] 30 Ralph Adams Cram	Boston
33 Cyrus Edwin Dallin	Arlington Heights
34 Samuel Foster Damon	Providence, R. I.
32 George Harold Edgell	Cambridge
21 William Emerson	Cambridge
33 Carl Engel	New York, N. Y.
30 John Erskine	New York, N. Y.
10 Arthur Fairbanks	Hanover, N. H.
18 Edward Waldo Forbes	Cambridge
31 Robert Frost	South Shaftsbury, Vt.
27 Wallace Goodrich	Boston
14 Robert Grant	Boston
36 William Clifford Heilman	Cambridge
29 Edward Burlingame Hill	Boston
31 Robert Silliman Hillyer	Cambridge
27 Charles Hopkinson	Manchester
12 Mark Antony DeWolfe Howe	Boston
38 Joseph Hudnut	Boston
18 Archer Milton Huntington	New York, N. Y.
31 Henry James	New York, N. Y.
(25) 32 William James	Cambridge
38 Howard Mumford Jones	Cambridge
33 Leo Rich Lewis	Tufts College
20 John Ellerton Lodge	Washington, D. C.
21 John Livingston Lowes	Cambridge
21 Charles Donagh Maginnis	Brookline
31 Paul Manship	New York, N. Y.
31 Daniel Gregory Mason	New York, N. Y.
31 Frank Jewett Mather	Washington Crossing, Pa.
31 Kenneth Ballard Murdock	Cambridge
14 William Allan Neilson	Northampton
28 Curtis Hidden Page	Gilmanton, N. H.
21 William Lyon Phelps	New Haven, Conn.
(24) 32 Anthony John Philpott	Arlington
21 Chandler Rathfon Post	Cambridge
22 Paul Joseph Sachs	Cambridge
14 Ellery Sedgwick	Boston
19 Henry Dwight Sedgwick	Dedham
33 David Stanley Smith	Woodbridge, Conn.
35 Walter Raymond Spalding	Cambridge
38 Grenville Lindall Winthrop	Lenox
22 Charles Henry Conrad Wright	Cambridge

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CLASS I—MATHEMATICAL AND PHYSICAL SCIENCES—32

SECTION I—*Mathematics and Astronomy*—9

22	Sir Arthur Stanley Eddington	Cambridge, England
34	Ronald Aylmer Fisher	Harpenden, Herts
20	Jacques Salomon Hadamard	Paris
21	Godfrey Harold Hardy	Cambridge, England
27	Ejnar Hertzsprung	Leyden
17	Tullio Levi-Civita	Rome
03	Charles Émile Picard	Paris
15	Charles Jean de la Vallée Poussin	Louvain
29	Hermann Weyl	Princeton, N. J.

CLASS I, SECTION II—*Physics*—8

29	Vilhelm Frimann Koren Bjerknes	Oslo
24	Albert Einstein	Princeton, N. J.
29	James Franck	Baltimore, Md.
29	Abram F. Joffé	Leningrad
03	Sir Joseph Larmor	Cambridge, England
28	Friedrich Paschen	Charlottenburg
14	Max Planck	Berlin
02	Sir Joseph John Thomson	Cambridge, England

CLASS I, SECTION III—*Chemistry*—9

29	Johannes N. Brönsted	Copenhagen
27	Peter Debye	Berlin
33	Jaroslav Heyrovsky	Prague
33	Fritz Paneth	London
38	Leopold Ruzicka	Zürich
38	Nevil Vincent Sidgwick	Oxford
28	Sören Peter Lauritz Sörensen	Copenhagen
29	Heinrich Wieland	Munich
34	Richard Willstätter	Munich

CLASS I, SECTION IV—*Technology and Engineering*—6

36	Edward Victor Appleton	Cambridge, England
34	Luigi Lombardi	Rome
29	Ludwig Prandtl	Göttingen
29	Emil Probst	Karlsruhe
29	Aurel Stodola	Zürich
31	Karl Willy Wagner	Berlin

CLASS II—NATURAL AND PHYSIOLOGICAL SCIENCES—32

SECTION I—*Geology, Mineralogy, and Physics of the Globe*—9

17	Frank Dawson Adams	Montreal
[15] 19	Charles Barrois	Lille
36	Raoul Blanchard	Grenoble, France
14	Waldemar Christofer Brögger	Oslo
29	Léon William Collet	Geneva
34	Arthur Holmes	Durham
22	Emmanuel de Margerie	Paris
21	Gustaf Adolf Frederik Molengraaff	Delft
18	Sir William Napier Shaw	London

CLASS II, SECTION II—*Botany*—6

32	Frederick Orpen Bower	Ripon
31	Ludwig Diels	Berlin
32	Kingo Miyabe	Sapporo, Japan
29	Otto Renner	Jena
32	Sir Albert Charles Seward	London
35	Sir William Wright Smith	Edinburgh

CLASS II, SECTION III—*Zoology and Physiology*—10

38	Edgar Douglas Adrian	Cambridge, England
38	Sir Joseph Barcroft	Cambridge, England
20	Maurice Caullery	Paris
38	Emmanuel Fauré-Frémiet	Paris
34	Archibald Vivian Hill	London
31	August Krogh	Copenhagen
30	Louis Édouard Lapicque	Paris
28	Charles Tate Regan	Feltham, Middlesex
33	Hans Spemann	Freiburg i. Br.
28	Sir D'Arcy Wentworth Thompson	St. Andrews

CLASS II, SECTION IV—*Medicine and Surgery*—7

18	Sir Thomas Barlow, Bart	London
27	Sir Henry Hallett Dale	London
33	Sir Arthur Keith	London
28	Mikinosuke Miyajima	Tokyo
27	Friedrich von Müller	Munich
18	Sir Charles Scott Sherrington	Ipswich, England
36	(Jean) Hyacinthe Vincent	Paris

CLASS III—THE SOCIAL ARTS—28

SECTION I—*Jurisprudence*—11

38	William Warwick Buckland	Cambridge, England
38	Mircea Djuvara	Bucharest
27	Léon Duguit	Bordeaux
33	François Geny	Nancy
38	Arthur Lehman Goodhart	Oxford
33	Hans Kelsen	Vienna
38	Rt. Hon. Lord Macmillan	London
33	Juljusz Makarewicz	Lwów
33	Rudolph Stammler	Wernigerode a. H.
33	Giorgio Del Vecchio	Rome
38	Rt. Hon. Lord Wright	London

SECTION II—*Government, International Law, and Diplomacy*—4

38	Dionisio Anzilotti	Rome
32	Paul Claudel	Paris
32	Hu Shih	Peiping
38	Kenzo Takayanagi	Tokyo

SECTION III—*Economics and Sociology*—11

32	Arthur Lyon Bowley	Haslemere, Surrey
34	Gustav Cassel	Djursholm, Sweden
35	Luigi Einaudi	Turin
32	Ralph George Hawtrey	London
35	John Maynard Keynes	Cambridge, England
35	René Maunier	Paris
28	Arthur Cecil Pigou	Cambridge, England
32	Charles Rist	Fraisses (Loire)
33	Werner Sombart	Berlin
35	S. Rudolph Steinmetz	Amsterdam
34	Peter B. Struve	Belgrade

SECTION IV—*Administration and Affairs*—2

33	Gösta A. Bagge	Stockholm
33	Josiah Charles Stamp, Baron Stamp	Shortlands, Kent

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SECTION I—*Theology, Philosophy, and Psychology*—8

36	Miguel Asín y Palacios	Madrid
28	Henri Louis Bergson	Paris
28	Benedetto Croce	Naples
29	Étienne Gilson	Melun
28	Edmund Husserl	Freiburg i. B.
32	Pierre Janet	Paris
28	Wolfgang Köhler	Berlin
37	Henri Pieron	Paris

SECTION II—*History, Archaeology, and Anthropology*—9

33	Rafael Altamira y Crevea	Madrid
36	Marcel Aubert	Paris
29	Godfrey R. Benson, Baron Charnwood	London
97	Wilhelm Dörpfeld	Berlin-Lichterfelde
31	Rt. Hon. Herbert Albert Laurens Fisher	Oxford
33	Friedrich Meinecke	Berlin-Dahlem
22	Henri Pirenne	Uccle-Brussels
30	Sir Aurel Stein	Srinagar, Kashmir
31	George Macaulay Trevelyan	Cambridge, England

SECTION III—*Philology*—6

09	Hermann Georg Jacobi	Bonn
36	Paul Kretschmer	Vienna
32	Paul Mazon	Paris
[12] 28	Hanns Oertel	Munich
17	Ramón Menéndez Pidal	Madrid
32	Frederick William Thomas	Oxford

SECTION IV—*The Fine Arts and Belles Lettres*—7

30	Alfredo Casella	Rome
23	Henry Guy	Grenoble
29	Paul Hazard	Paris
34	Serge Koussevitzky	Paris and Boston
27	Gilbert Murray	Oxford
31	Edgar Allison Peers	Liverpool
27	Henri Rabaud	Paris

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Batchelder, C. F. F, III: 4
Bates, H. M. F, III: 1
Bates, W. N. F, IV: 3
Baxter, G. P. F, I: 3
Baxter, J. P., 3d. F, IV: 2
Beale, J. H. F, III: 1
Beattie, J. A. F, I: 3
Becker, C. L. F, IV: 2
Beebe-Center, J. G. F, IV: 1
Beeson, C. H. F, IV: 3
Bell, S. F, III: 1
Benedict, F. G. F, II: 3
Benét, S. V. F, IV: 4
Bennett, A. A. F, I: 1
Benson, F. W. F, IV: 4
Bergson, H. L. FHM, IV: 1
Berry, C. H. F, I: 4
Berry, E. W. F, II: 2
Bevis, H. L. F, III: 2
Bigelow, H. A. F, III: 1
Bigelow, H. B. F, II: 3
Bigelow, R. P. F, II: 3
Biklé, H. W. F, III: 1
Billings, M. P. F, II: 1
Birkhoff, G. D. F, I: 1
Bixler, J. S. F, IV: 1
Bjerknes, V. F. K. FHM, I: 2
Blake, C. H. F, II: 3
Blake, R. P. F, IV: 2
Blanchard, A. A. F, I: 3
Blanchard, R. FHM, II: 1
Bliss, G. A. F, I: 1
Blumer, G. F, II: 4
Boas, F. F, IV: 2
Bogert, M. T. F, I: 3
Bolster, W. F, III: 1
Bonbright, J. C. F, III: 3
Bonner, C. F, IV: 3
Bonner, R. J. F, IV: 3
Booth, H. S. F, I: 3
Borchard, E. M. F, III: 2
Boring, E. G. F, IV: 1
Bosworth, W. F, IV: 1
Bovie, W. T. F, II: 3
Bowen, N. L. F, II: 1
Bower, F. O. FHM, II: 2
Bowley, A. L. FHM, III: 3
Bowman, I. F, II: 1
Boyden, E. A. F, II: 3
Branch, C. R. F, III: 1
Bray, W. C. F, I: 3
Bremer, J. L. F, II: 3
Bridgman, P. W. F, I: 2
Brightman, E. S. F, IV: 1
Brögger, W. C. FHM, II: 1
Brönsted, J. N. FHM, I: 3
Brooks, C. F. F, II: 1
Brown, C. F, IV: 3
Bruce, H. A. F, IV: 1
Brues, C. T. F, II: 3
Bryan, K. F, II: 1
Buck, C. D. F, IV: 3
Buckland, W. W. FHM, III: 1
Bunker, J. W. M. F, II: 3
Burbank, H. H. F, III: 3
Burwell, C. S. F, II: 4
Bush, V. F, I: 4
Cabot, P. F, III: 3
Cabot, W. B. F, IV: 2
Cady, W. G. F, I: 2
Campbell, C. G. F, IV: 2
Campbell, C. M. F, II: 4
Campbell, D. H. F, II: 2
Campbell, G. A. F, I: 2
Campbell, L. L. F, I: 2
Cannon, W. B. F, II: 3
Capps, E. F, IV: 3
Carmichael, L. F, IV: I
Carpenter, F. M. F, II: 1
Carpenter, J. A. F, IV: 4
Carpenter, T. M. F, II: 3
Carrel, A. F, II: 4
Casella, A. FHM, IV: 4
Casey, R. P. F, IV: 1
Cassel, G. FHM, III: 3
Castle, W. B. F, II: 4
Castle, W. E. F, II: 3
Castle, W. R., Jr. F, III: 2
Cattell, J. M. F, IV: 1
Caullery, M. FHM, II: 3
Chaffee, E. L. F I: 2
Chamberlain, J. P. F, III: 2
Chamberlin, D. H. F. III: 3
Chamot, E. M. F, I: 3
Chapin, C. V. F, II: 4
Charnwood, Lord. FHM, IV: 2
Chase, G. H. F, IV: 2
Cheever, D. F, II: 4
Chittenden, R. H. F, I: 3
Christian, H. A. F, II: 4
Clark, J. M. F, III: 3
Clark, W. E. F, IV: 3
Claudel, P. FHM, III: 2
Clayton, H. H. F, II: 1

Cleveland, L. R. F, II: 3
Clifton, C. D. F, IV: 4
Cohn, E. J. F, II: 3
Cole, A. H. F, III: 3
Cole, R. F, II: 4
Collens, C. F, IV: 4
Collet, L. W. FHM, II: 1
Compton, A. H. F, I: 2
Compton, K. T. F, I: 2
Comstock, D. F. F, I: 2
Conant, J. B. F, I: 3
Conant, K. J. F, IV: 4
Conklin, E. G. F, II: 3
Connick, C. J. F, IV: 4
Coolidge, J. L. F, I: 1
Coolidge, W. D. F, I: 2
Copeland, C. T. F, IV: 4
Copeland, M. F, II: 3
Copeland, M. T. F, III: 3
Cram, R. A. F. IV: 4
Crane, R. S. F, IV: 3
Crane, R. T. F, III: 2
Crawford, F. H. F, I: 2
Crawford, J. P. W. F, IV: 3
Crew, H. F, I: 2
Croce, B. FHM, IV: 1
Croll, M. W. F, IV: 3
Cross, S. H. F, IV: 3
Crozier, W. J. F, II: 3
Crum, W. L. F, III: 3
Cunningham, W. J. F, III: 3
Cushing, H. F, II: 4
Cushman, J. A. F, II: 3
Cutler, E. C. F, II: 4
Dahl, O. G. C. F, I: 4
Dale, Sir H. H. FHM, II: 4
Dallin, C. E. F, IV: 4
Daly, R. A. F, II: 1
Damon, S. F. F, IV: 4
Daniel, J. F. F, II: 3
Daniels, W. M. F, III: 3
Davenport, C. B. F, II: 3
Davis, B. M. F, II: 2
Davis, H. F, II: 3
Davis, H. N. F, I: 2
Davis, T. L. F, I: 3
Davisson, C. J. F, I: 2
Dawes, C. L. F, I: 4
Dawson, A. B. F, II: 3
Day, A. L. F, I: 2
Day, C. F, III: 3
Day, E. E. F, III: 4
Dearborn, W. F. F, IV: 1
Debye, P. FHM, I: 3
de Forest, A. V. F, I: 4
Delabarre, E. B. F, IV: 1
Den Hartog, J. P. F, I: 4
Dennett, T. F, III: 2
Dennison, H. S. F, III: 4
Detwiler, S. R. F, II: 3
Dewey, D. R. F, III: 3
Dewing, A. S. F, III: 3
Dickinson, J. F, III: 1
Dickson, L. E. F, I: 1
Diels, L. FHM, II: 2
Dillon, T. H. F, I: 4
Djuvara, M. FHM, III: 1
Dodge, B. O. F, II: 2
Dodge, R. F, IV: 1
Dodge, R. G. F, III: 1
Dörpfeld, W. FHM, IV: 2
Donham, W. B. F, III: 3
Douglas, J. F, I: 1
Drinker, P. F, I: 4
Drisko, W. J. F, I: 2
Du Bois, E. F. F, II: 4
Ducasse, C. J. F, IV: 1
Duff, A. W. F, I: 2
Duguit, L. FHM, III: 1
Duncan, J. C. F. I: 1
Dunn, G. F, I: 4
Durand, W. F. F, I: 4
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Eddington, Sir A. S. FHM, I: 1
Edgell, G. H. F, IV: 4
Edgerton, F. F, IV: 3
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Einaudi, L. FHM, III: 3
Einstein, A. FHM, I: 2
Emerson, R. A. F, II: 2
Emerson, W. F, IV: 4
Engel, C. F, IV: 4
Erskine, J. F, IV: 4
Esselen, G. J. F, I: 3
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Evans, G. C. F, I: 1
Evans, H. M. F, II: 3
Ewell, A. W. F, I: 2
Fair, G. M. F, I: 4
Fairbanks, A. F, IV: 4
Fairchild, F. R. F, III: 3
Fall, H. C. F, II: 3
Farley, F. E. F, IV: 3
Farrand, M. F, IV: 2
Faull, J. H. F, II: 2
Fauré-Frémiet, E. FHM, II: 3
Fay, F. H. F, I: 4
Fay, H. F, I: 3
Fay, S. B. F, III: 2
Ferguson, W. S. F, IV: 2
Fergusson, S. P. F, II: 1
Fernald, M. L. F, II: 2
Fetter, F. A. F, III: 3
Field, F. T. F, III: 1
Field, W. L. W. F, III: 4
Fieser, L. F. F, I: 3
Fisher, H. A. L. FHM, IV: 2
Fisher, I. F, III: 3
Fisher, R. A. FHM, I: 1
Fiske, C. H. F, II: 3
Fitz, R. F, II: 4
Flexner, S. F, II: 4
Forbes, A. F, II: 3
Forbes, A. B. F, IV: 2
Forbes, E. W. F, IV: 4
Forbes, G. S. F, I: 3
Forbes, W. C. F, III: 2
Ford, H. S. F, III: 4
Ford, J. F, III: 3
Ford, J. D. M. F, IV: 3
Ford, W. C. F, IV: 2
Ford, W. E. F, II: 1
Fowler, H. T. F, IV: 2
Fox, P. F, I: 1
Frame, J. E. F, IV: 1
Franck, J. FHM, I: 2
Frank, T. F, IV: 3
Frankfurter, F. F, III: 1
Franklin, P. F, I: 1
Freeman, R. E. F, III: 3
Frost, R. F, IV: 4
Fuess, C. M. F, IV: 2
Fulton, J. F. F, II: 3
Furniss, E. S. F, III: 2
Gamble, J. L. F, II: 4
Gay, E. F. F, III: 3
Geddes, J., Jr. F, IV: 3
Geny, F. FHM, III: 1
Gilboy, G. F, I: 4
Gillespie, L. J. F, I: 3
Gilson, E. FHM, IV: 1
Glueck, S. F, III: 3
Goldthwait, J. W. F, II: 1
Goodale, J. L. F, II: 4
Goodhart, A. L. FHM, III: 1
Goodnow, F. J. F, III: 4
Goodrich, W. F, IV: 4
Goodwin, H. M. F, I: 2
Graham, C. H. F, IV: 1
Grandgent, C. H. F, IV: 3
Grant, R. F, IV: 4
Graton, L. C. F, II: 1
Graustein, W. C. F, I: 1
Gray, L. H. F, IV: 3
Green, T. F. F, III: 1
Greene, E. B. F, IV: 2
Greene, J. D. F, III: 4
Greene, W. C. F, IV: 3
Gregory, H. E. F, II: 1
Gregory, W. K. F, II: 3
Grew, J. C. F, III: 2
Grinnell, F. W. F, III: 1
Grinnell, J. F, II: 3
Gulick, C. B. F, IV: 3
Guy, H. FHM, IV: 4
Hack, R. K. F, IV: 3
Hadamard, J. S. FHM, I: 1

Haertlein, A. F, I: 4
Haig, R. M. F, III: 3
Haines, C. G. F, III: 2
Hand, L. F, III: 1
Hardy, A. C. F, I: 2
Hardy, G. H. FHM, I: 1
Harmon, A. M. F, IV: 3
Harper, R. A. F, II: 2
Harris, L. F, I: 3
Harrison, G. R. F, I: 2
Harrison, R. G. F, II: 4
Hart, A. B. F, III: 2
Hastings, A. B. F, I: 3
Hatch, W. H. P. F, IV: 1
Havens, R. D. F, IV: 3
Hawkins, R. L. F, IV: 3
Hawtrey, R. G. FHM, III: 3
Hayes, H. V. F, I: 2
Hazard, P. FHM, IV: 4
Hazen, C. D. F, IV: 2
Healy, W. F, IV: 1
Heidel, W. A. F, IV: 1
Heilman, W. C. F, IV: 4
Henderson, L. J. F, I: 3
Hendrickson, G. L. F, IV: 3
Henshaw, S. F, II: 3
Hertzsprung, E. FHM, I: 1
Heyrovsky, J. FHM, I: 3
Hill, A. V. FHM, II: 3
Hill, B. H. F, IV: 2
Hill, E. B. F, IV: 4
Hille, E. F, I: 1
Hillyer, R. S. F, IV: 4
Hisaw, F. L. F, II: 3
Hitchcock, F. L. F, I: 1
Hoadley, L. F, II: 3
Hoagland, H. F, II: 3
Hockett, R. C. F, I: 3
Hocking, W. E. F, IV: 1
Holcombe, A. N. F, III: 2
Holmes, A. FHM, II: 1
Holmes, E. J. F, III: 4
Holmes, H. W. F, III: 3
Holmes, S. J. F, II: 3
Hooton, E. A. F, IV: 2
Hopkinson, C. F, IV: 4
Horwood, M. P. F, I: 4
Hoskins, H. L. F, IV: 2
Hoskins, R. G. F, II: 3
Hovgaard, W. F, I: 4
Howard, L. O. F, II: 3
Howard, W. G. F, IV: 3
Howe, M. A. DeW. F, IV: 4
Howe, P. R. F, II: 4
Howell, W. H. F, II: 4
Hrdlička, A. F, IV: 2
Hu Shih. FHM, III: 2
Hubbard, J. C. F, I: 2
Hudnut, J. F, IV: 4
Hudson, M. O. F, III: 2
Hughes, C. E. F, III: 1
Hull, C. L. F, IV: 1
Hull, G. F. F, I: 2
Hume, E. E. F, II: 4
Humphreys, W. J. F, II: 1
Hunsaker, J. C. F, I: 4
Hunt, R. F, II: 4
Hunter, W. S. F, IV: 1
Huntington, A. M. F, IV: 4
Huntington, E. F, II: 1
Huntington, E. V. F, I: 1
Huntress, E. H. F, I: 3
Husserl, E. FHM, IV: 1
Hutchins, C. C. F, I: 2
Hyvernat, E. X. L. H. F, IV: 3
Isaacs, N. F, III: 1
Ives, J. E. F, I: 2
Jack, J. G. F, II: 2
Jack, J. R. F, I: 4
Jackson, C. N. F, IV: 3
Jackson, D. F, I: 1
Jackson, D. C. F, I: 4
Jackson, F. J. F. F, IV: 1
Jackson, H., Jr. F, II: 4
Jackson, R. T. F, II: 1
Jacobi, H. G. FHM, IV: 3
Jaggar, T. A. F, II: 1
James, H. F, IV: 4
James, W. F, IV: 4
Janet, P. FHM, IV: 1
Jellinek, E. M. F, I: 1
Jennings, H. S. F, II: 3
Jennings, W. L. F, I: 3
Jepson, W. L. F, II: 2
Jessup, P. C. F, III: 2
Jewett, F. B. F, I: 4
Jewett, J. R. F, IV: 3
Joffé, A. F. FHM, I: 2
Johnson, D. W. F, II: 1
Johnson, L. J. F, I: 4
Johnson, M. M. F, III: 1
Johnston, I. M. F, II: 2
Jones, D. F. F, II: 2
Jones, G. F, I: 3
Jones, H. M. F, IV: 4
Jones, M. B. F, III: 4
Joslin, E. P. F, II: 4
Keenan, J. H. F, I: 4
Keith, Sir A. FHM, II: 4
Keith, A. F, II: 1
Kelsen, H. FHM, III: 1
Kemble, E. C. F, I: 2
Kemmerer, E. W. F, III: 3
Kendall, H. P. F, III: 4
Keniston, H. F, IV: 3
Kennelly, A. E. F, I: 4
Kent, N. A. F, I: 2
Kent, R. G. F, IV: 3
Keyes, F. G. F, I: 3
Keynes, J. M. FHM, III: 3
Kistiakowsky, G. B. F, I: 3
Kittredge, G. L. F, IV: 3
Knight, F. H. F, III: 3
Knudson, A. C. F, IV: 1
Köhler, W. FHM, IV: 1
Koffka, K. F, IV: 1
Kofoid, C. A. F, II: 3
Koussevitzky, S. FHM: IV, 4
Kraus, C. A. F, I: 3
Kretschmer, P. FHM, IV: 3
Kroeber, A. L. F, IV: 2
Krogh, A. FHM, II: 3
Kurath, H. F, IV: 3
Lake, K. F, IV: 2
Lamb, A. B. F, I: 3
Lamont, T. W. F, III: 4
Lampland, C. O. F, I: 1
Landis, J. M. F, III: 1
Lane, A. C. F, II: 1
Langley, E. F. F, IV: 3
Langmuir, I. F, I: 3
Lanman, C. R. F, IV: 3
La Piana, G. F, IV: 2
Lapicque, L. E. FHM, II: 3
Larmor, Sir J. FHM, I: 2
Larsen, E. S. F, II: 1
Lashley, K. S. F, IV: 1
Lawrence, E. O. F, I: 2
Lawrence, R. R. F, I: 4
Lawrence, W. F, IV: 1
Lawrence, W. H. F, I: 4
Lawson, A. C. F, II: 1
Lawton, F. F, III: 1
Lee R. I. F, II: 4
Lefavour, H. F, I: 2
Leith, C. K. F, II: 1
Leland, W. G. F, IV: 2
Lessells, J. M. F, I: 4
Levi-Civita, T. FHM, I: 1
Lewis, C. I. F, IV: 1
Lewis, F. T. F, II: 3
Lewis, G. N. F, I: 3
Lewis, L. R. F, IV: 4
Lewis, W. K. F, I: 3
Lillie, F. R. F, II: 3
Lillie, R. S. F, II: 3
Lindgren, W. F, II: 1
Lindsay, R. B. F, I: 2
Linforth, I. M. F, IV: 3
Lipman, J. G. F, II: 2
Little, C. C. F, III: 4
Livingston, B. E. F, II: 2
Locke, E. A. F, II: 4
Lodge, J. E. F, IV: 4
Lombardi, L. FHM, I: 4
Longcope, W. T. F, II: 4
Lowell, A. L. F, III: 2

Lowes, J. L. F, IV: 4
Lull, R. S. F, II: 3
Lund, F. B. F, II: 4
Luyten, W. J. F, I: 1
Lyman, T. F, I: 2
McAdie, A. G. F, II: 1
McCollester, L. S. F, IV: 1
McCrea, R. C. F, III: 3
McEwen, G. F. F, II: 1
McIlwain, C. H. F, IV: 2
MacInnes, D. A. F, I: 3
MacIver, R. M. F, III: 3
McKeehan, L. W. F, I: 2
McLaren, W. W. F, III: 3
McLaughlin, D. H. F, II: 1
Macmillan, Lord. FHM, III: 1
McNair, M. P. F, III: 3
Macneil, S. F, III: 1
Maginnis, C. D. F, IV: 4
Magruder, C. F, III: 1
Main, C. T. F, I: 4
Makarewicz, J. FHM, III: 1
Mallory, F. B. F, II: 4
Malone, D. F, III: 4
Manship, P. F, IV: 4
Margerie, E. de. FHM, II: 1
Mark, E. L. F, II: 3
Mark, K. L. F, I: 3
Marks, L. S. F, I: 4
Marshall, L. C. F, III: 3
Mason, D. G. F, IV: 4
Mason, E. S. F, III: 3
Mather, F. J. F, IV: 4
Mather, K. F. F, II: 1
Mathews, E. B. F, II: 1
Matthews, A. F, IV: 3
Maunier, R. FHM, III: 3
May, J. V. F, III: 4
Mayo, E. F, III: 3
Mayo, W. J. F, II: 4
Mazon, P. FHM, IV: 3
Mead, A. D. F, II: 3
Mead, W. J. F, II: 1
Meinecke, F. FHM, IV: 2
Melander, A. L. F, II: 3
Menzel, D. H. F, I: 1
Meriam, R. S. F, III: 3
Meritt, B. D. F, IV: 3
Merriam, C. E. F, III: 2
Merriam, J. C. F, II: 1
Merrill, E. D. F, II: 2
Merriman, R. B. F, IV: 2
Merritt, E. G. F, I: 2
Meyer, K. F. F, II: 3
Milas, N. A. F, I: 3
Miller, D. C. F, I: 2
Miller, G. A. F, I: 1
Miller, G. S. F, II: 3
Miller, J. A. F, I: 1
Miller, W. J. F, II: 1
Millikan, R. A. F, I: 2
Millis, H. A. F, III: 3
Mills, F. C. F, III: 3
Mimno, H. R. F, I: 2
Miner, L. M. S. F, II: 4
Minot, G. R. F, II: 4
Mitchell, S. F, IV: 2
Mitchell, S. A. F, I: 1
Mitchell, W. C. F, III: 3
Mitchell, W. DeW. F, III: 1
Miyabe, K. FHM, II: 2
Miyajima, M. FHM, II: 4
Molengraaff, G. A. F. FHM, II: 1
Monroe, A. E. F, III: 3
Moore, E. C. F, IV: 1
Moore, J. B. F, III: 2
Moreland, E. L. F, I: 4
Morgan, E. M. F, III: 1
Morgan, T. H. F, II: 3
Morison, S. E. F, IV: 2
Morris, F. K. F, II: 1
Morse, M. F, I: 1
Morse, P. M. F, I: 2
Morton, A. A. F, I: 3
Morton, J. M. F, III: 1
Moss, W. L. F, II: 4
Moulton, F. R. F, I: 1
Moulton, H. G. F, III: 3
Mueller, E. F, I: 3
Müller, F. von. FHM, II: 4
Mueller, J. H. F, II: 4
Munro, W. B. F, III: 2
Murdock, K. B. F, IV: 4
Murray, G. FHM, IV: 4
Murray, H. A., Jr. F, IV: 1
Neal, H. V. F, II: 3
Neilson, W. A. F, IV: 4
Newhouse, W. H. F, II: 1
Nitze, W. A. F, IV: 3
Nock, A. D. F, IV: 1
Norris, J. F. F, I: 3
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Nourse, E. G. F, III: 3
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O'Connell, W. H. F, IV: 1
O'Connor, J. F, IV: 1
Oertel, H. FHM, IV: 3
Ogburn, W. F. F, III: 3
Oldenberg, O. F, I: 2
Oldfather, W. A. F, IV: 3
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Osterhout, W. J. V. F, II: 2
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Palmer, W. W. F, II: 4
Paneth, F. FHM, I: 3
Park, C. E. F, IV: 1
Park, C. F. F, I: 4
Park, R. E. F, III: 3
Parker, G. H. F, II: 3
Parker, P. S. F, III: 1
Parkman, H., Jr. F, III: 1
Paschen, F. FHM, I: 2
Patch, H. R. F, IV: 3
Pearl, R. F, II: 3
Pearse, L. F, I: 4
Pease, A. S. F, IV: 3
Peers, E. A. FHM, IV: 4
Peirce, G. J. F, II: 2
Pender, H. F, I: 4
Pepper, G. W. F, III: 1
Pfeiffer, R. H. F, IV: 2
Phelps, W. L. F, IV: 4
Phillips, H. B. F, I: 1
Philpott, A. J. F, IV: 4
Picard, C. E. FHM, I: 1
Pickard, G. W. F, I: 4
Pidal, R. M. FHM, IV: 3
Pierce, G. W. F, I: 2
Piéron, H. FHM, IV: 1
Pigou, A. C. FHM, III: 3
Pilsbry, H. A. F, II: 3
Pirenne, H. FHM, IV: 2
Planck, M. FHM, I: 2
Poor, C. L. F, I: 1
Post, C. R. F, IV: 4
Pound, R. F, III: 1
Prandtl, L. FHM, I: 4
Pratt, C. C. F, IV: 1
Pratt, F. H. F, II: 3
Pratt, J. H. F, II: 4
Prescott, H. W. F, IV: 3
Prescott, S. C. F, I: 3
Prest, W. M. F, III: 1
Probst, E. FHM, I: 4
Putnam, H. F, III: 4
Putnam, T. J. F, II: 4
Qua, S. E. F, III: 1
Quinby, W. C. F, II: 4
Rabaud, H. FHM, IV: 4
Rand, E. K. F, IV: 3
Rand, H. W. F, II: 3
Rapport, D. F, II: 3
Raymond, P. E. F, II: 1
Redfield, A. C. F, II: 3
Regan, C. T. FHM, II: 3
Rehder, A. F, II: 2
Reisner, G. A. F, IV: 2
Renner, O. FHM, II: 2
Richards, A. N. F, II: 3
Richards, R. H. F, I: 3
Richardson, R. G. D. F, I: 1

Richtmyer, F. K. F, I: 2
Riddle, O. F, II: 3
Ripley, A. L. F, III: 4
Rist, C. FHM, III: 3
Ritter, W. E. F, II: 3
Robinson, D. M. F, IV: 2
Robinson, F. N. F, IV: 3
Rogers, A. F. F, II: 1
Rollins, H. E. F, IV: 3
Romer, A. S. F, II: 3
Root, R. K. F, IV: 3
Rosanoff, M. A. F, I: 3
Rossby, C. G. A. F, II: 1
Rostovtzeff, M. I. F, IV: 2
Rowe, L. S. F, III: 3
Ruggles, A. H. F, II: 4
Ruggles, O. C. F, III: 3
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Rutledge, G. F, I: 1
Ruzicka, L. FHM, I: 3
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Sachs, P. J. F, IV: 4
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Sarton, G. F, IV: 2
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Sax, K. F, II: 2
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Sayre, F. B. F, III: 1
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Schaller, W. T. F, II: 1
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Schumb, W. C. F, I: 3
Schumpeter, J. A. F, III: 3
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Scott, D. F, IV: 2
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Scott, W. B. F, II: 1
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Sedgwick, H. D. F, IV: 4
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Setchell, W. A. F, II: 2
Seward, Sir A. C. FHM, II: 2
Seymour, C. F, III: 4
Shapley, H. F, I: 1
Shattuck, G. C. F, II: 4
Shattuck, H. L. F, III: 4
Shaw, H. S. F, III: 4
Shaw, Sir W. N. FHM, II: 1
Shear, T. L. F, IV: 2
Sherrill, H. K. F, IV: 1
Sherrill, M. S. F, I: 3
Sherrington, Sir C. S. FHM, II: 4
Shimer, H. W. F, II: 1
Sidgwick, N. V. FHM, I: 3
Simpson, S. P. F, III: 1
Sinnott, E. W. F, II: 2
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Smith, H. E. F, IV: 3
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Smith, L. B. F, I: 3
Smith, P. F, III: 4
Smith, Sir W. W. FHM, II: 2
Smyth, H. L. F, I: 4
Snyder, C. F, III: 3
Snyder, V. F, I: 1
Sörensen, S. P. L. FHM, I: 3
Sollmann, T. H. F, II: 4
Sombart, W. FHM, III: 3
Sorokin, P. A. F, III: 3
Spalding, W. R. F, IV: 4
Spemann, H. FHM, II: 3
Sperry, W. L. F, IV: 1
Spinden, H. J. F, IV: 2
Spofford, C. M. F, I: 4
Sprague, O. M. W. F, III: 3
Stafford, R. H. F, IV: 1
Stakman, E. C. F, II: 2
Stammler, R. FHM, II: 1
Stamp, Baron. FHM, III: 4
Sterns, A. W. F, III: 4
Stebbins, J. F, I: 1
Stein, Sir A. FHM, IV: 2
Steinmetz, S. R. FHM, III: 3
Stephenson, F. B. F, IV: 3
Stetson, H. T. F, I: 1
Stevens, J. F. F, I: 4
Stewart, G. W. F, I: 2
Stiles, C. W. F, II: 4
Stodola, A. FHM, I: 4
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Stone, J. S. F, I: 2
Stone, M. H. F, I: 1
Street, J. C. F, I: 2
Strong, R. P. F, II: 4
Struik, D. J. F, I: 1
Struve, P. B. FHM, III: 3
Takayanagi, K. FHM, III: 1
Talbot, F. B. F, II: 4
Tamarkin, J. D. F, I: 1
Taussig, F. W. F, III: 3
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Taylor, C. H. F, IV: 2
Teggart, F. J. F, III: 3
Terman, L. M. F, IV: 1
Thimann, K. V. F, II: 2
Thomas, F. W. FHM, IV: 3
Thomas, W. I. F, III: 3
Thompson, Sir D'A. W. FHM, II: 3
Thompson, M. deK. F, I: 2
Thomson, Sir J. J. FHM, I: 2
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Thurston, E. S. F, III: 1
Thurstone, L. L. F, IV: 1
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Torrey, C. C. F, IV: 3
Tosdal, H. R. F, III: 3
Tozzer, A. M. F, IV: 2
Trelease, W. F, II: 2
Trevelyan, G. M. FHM, IV: 2
Tucker, D. S. F, III: 3
Turner, C. E. F, III: 4
Tyzzer, E. E. F, II: 4
Urey, H. C. F, I: 3
Usher, A. P. F, III: 3
Vallarta, M. S. F, I: 2
Vallée Poussin, C. J. de la. FHM, I: 1
Van de Graaff, R. J. F, I: 2
Van Vleck, J. H. F, I: 2
Vaughan, T. W. F, II: 1
Veblen, O. F, I: 1
Vecchio, G. Del. FHM, III: 1
Verhoeff, F. H. F, II: 4
Vincent, J. H. FHM, II: 4
Viner, J. F, III: 3
Wagner, K. W. FHM, I: 4
Walsh, J. L. F, I: 1
Wambaugh, E. F, III: 1
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Warren, C. H. F, II: 1
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Washburn, H. B. F, IV: 1
Watson, J. B. F, IV: 1
Wearn, J. T. F, II: 4
Weatherby, C. A. F, II: 2
Webster, D. L. F, I: 2
Webster, E. S. F, III: 4
Weiss, S. F, II: 4
Wells, A. E. F, I: 4
Wells, F. L. F, IV: 1
Westergaard, H. M. F, I: 4
Weston, G. B. F, IV: 3
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Wetmore, R. H. F, II: 2
Weyl, H. FHM, I: 1
Weysse, A. W. F, II: 3
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Whitlock, H. P. F, II: 1
Whitman, E. A F, III: 1
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Widder, D. V. F, I: 1

Wieland, H. FHM, I: 3
Wilkins, E. H. F, IV: 3
Williams, J. H. F, III: 3
Williams, R. S. F, I: 3
Willis, B. F, II: 1
Willits, J. H. F, III: 3
Willoughby, W. F. F, III: 2
Willoughby, W. W. F, III: 2
Willstätter, R. FHM, I: 3
Wilson, E. B. F, II: 3
Wilson, E. B. F, I: 2
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Winthrop, G. L. F, IV: 4
Wislocki, G. B. F, II: 3
Wissler, C. F, IV: 2
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Wolff, J. E. F, II: 1
Wolfson, H. A. F, IV: 3
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Wood, R. W. F, I: 2
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Woodworth, R. S. F, IV: 1
Worcester, J. R. F, I: 4
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Wright, Lord. FHM, III: 1
Wright, C. H. C. F, IV: 4
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Wright, Q. F, III: 2
Wyman, J., Jr. F, II: 3
Yeomans, H. A. F, III: 2
Yerkes, R. M. F, IV: 1
Young, B. L. F, III: 4
Young, K. F, IV: 3
Zeleny, J. F, I: 2
Zimmerman, C. C. F, III: 3
Zinsser, H. F, II: 4

NEUROHUMORS AS CHROMATOPHORE ACTIVATORS

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I. Introduction

Neurohumors, neurohormones, and chemical activators are general terms applied to a group of substances believed to be concerned in the activation of the nervous system and its appended parts. They are supposed to be the means of transmitting from sense cell to neurone, from one neurone to another, and from neurone to effector cell those communicating functional activities that link together such cells into reflex arcs and other like chains of nervous interrelation. Such substances may be briefly said to be nervous hormones and to partake of the nature of true hormones as originally described by Bayliss and Starling (1902) except in that they are limited to the nervous field. That substances of this kind may exist was first shown, though without recognizing the full import of the matter, by Corona and Moroni in 1898 when they discovered that adrenalin on being injected into a frog would cause it to blanch. Lieben in 1906 independently rediscovered this phenomenon and added to its record the observation that this change in color was due to the contraction of melanophores. In 1918 Redfield pointed out the probable part normally played by adrenalin in the blanching of the lizard *Phrynosoma* since which time this agent has been looked upon as a likely neurohumor in various chromatic animals. Meanwhile the secretion of the intermediate lobe of the pituitary gland, intermedin, was beginning to attract attention as a dispersing neurohumor in amphibians (Smith, 1916a, 1916b; Allen, 1916), a view carried to great fullness by Hogben and his associates (Hogben and Winton, 1922a, 1922b; Hogben, 1924b). These advances were followed by similar discoveries in the chromatic activities of crustaceans. Perkins (1928), following an early observation by Koller (1925), reported in the same year with this worker (1928) that an extract of the eye-stalks of shrimps contained a material, a neurohumor, that when injected into a dark shrimp would induce it to blanch. Thus the neurohumoral hypothesis gained an ever broadening application among chromatic animals.

All these newer observations can be set off collectively against the older and more usual conception of a direct nervous control of chromatophores. Thus these later discoveries led workers like Hogben (1924b) to accept the view that chromatophores in different groups of animals were subject to different kinds of activation, in some instances nervous in others endocrinal or, as it would be designated today, neurohumoral. Hence there came a break with the older traditions, a break which may be set in general at about 1920, and which marks the introduction into this field of the novel agent, the neurohumor, which at least shared the responsibility with pure nerve action as a means of exciting chromatophore responses. The animals to which this interpretation of the excitation of color changes applied were certain crustaceans, particularly shrimps and prawns, and the lower vertebrates, fishes, amphibians, and lizards. The only other extensive group of forms in which color changes are significant is that of the cephalopods which includes such creatures as the octopus, the cuttlefish, and the squid. In these animals the chromatophores, which as a matter of fact are the particular effectors to which this name was originally applied (Sangiovanni, 1819), are much more complex than are those in the crustaceans and the vertebrates. In cephalopods the chromatophores are veritably miniature organs, for they consist each of a cellular sac of colored fluid surrounded by a circlet of innervated, smooth muscle-fibers by which the sac may be drawn out from its spherical form into a broad disc. On the relaxation of the muscle-fibers this sac whose wall is elastic reassumes its spherical shape and thus changes from a broad, circular, colored area into an inconspicuous dot. Plainly such a chromatophore, though serving the same purpose as the similarly named effectors in the crustaceans and the vertebrates, is structurally much more complex than are these which are either individual cells or at most small groups of cells. The neurohumoral problem in cephalopod chromatophores is that of the relation of nerve-fibers to smooth muscle-cells, the portion of the organ by which the color-sac is operated, whereas that in the crustaceans and the vertebrates has to do with nerve-fibers that impinge at once on color cells whose operations involve streaming protoplasm. The conditions in the crustaceans and the vertebrates, physiologically more primitive perhaps than those in the cephalopods, are what will be considered in the present account and nothing further will be said about cephalopod chromatophores and their complications.

II. CRUSTACEAN NEUROHUMORS

The crustaceans that exhibit color changes are found almost exclusively among the larger types, the malacostracans, and range from the isopods to the decapods. The first crustacean in which this activity was clearly observed was the prawn *Hippolyte* (Kröyer, 1842) and the earliest account of the crustacean chromatophore was drawn from the schizopod *Mysis* (Sars, 1867). The experimental study of color changes in crustaceans may be said to have been initiated in 1872 by Pouchet, and the subject was firmly established and greatly extended by Keeble and Gamble (1900–1905) in their classical investigations carried on during the early years of the present century.

A crustacean chromatophore consists usually of a group of closely associated cells or better perhaps a syncitium containing a number of nuclei. Its central mass, however, is often so divided as to suggest separate cells. In its expanded condition it possesses many long branching processes which reach out from its center into the adjacent tissue. In its contracted state these processes are said not to be visible with certainty. On reexpansion, however, the processes reproduce closely their original outlines as can be shown by successive photographs (Perkins, 1928). The central mass of the chromatophore contains a dense accumulation of pigment which in expansion passes out in part into the branched processes. This pigment may be of one or more kinds. In *Crangon* (Koller, 1927, 1928, 1930; Abramowitz, 1937b), *Portunus ordwayi* (Abramowitz, 1935c), *Uca pugilator* (Carlson, 1936) and the like four kinds of pigment are present,—yellow, red, black, and white. Some decapods have only three of these pigments; thus in *Uca pugnax* red is almost lacking, in *Portunus anceps* it is entirely so (Abramowitz, 1937b, 1935c) and in *Palaemonetes vulgaris* (Perkins, 1928; Brown, 1935) and in *Leander adspersus* (Hanström, 1937) black is absent. Two or even three kinds of pigments may be found in the same chromatophore. Thus di- and terchromatic chromatophores may occur, as, for instance, in *Hippolyte* and *Crangon* (Keeble and Gamble, 1900–1905), in *Palaemonetes* (Brown, 1935) and in other decapods. Scattered among these polychromatic chromatophores are also to be found color cells containing only one type of pigment. In *Portunus anceps* (Abramowitz, 1935c) the three pigments, white, black, and yellow, are always each in a separate chromatophore, and the same is true of the four pigments, dark, red, yellow, and white, in *Uca pugilator* (Carlson, 1936). Thus, though these crabs themselves may be said to be polychromatic, their individual chromatophores are monochromatic. The polychromatism which appears to characterize many species of decapods contrasts strongly with the monochromatic condition of the two isopods *Ligia oceanica* (Tait, 1910) and *L. baudiniana* (Kleinholz, 1937). Both these species may be said to possess only melanophores, for the "guanophores" described in *L. baudiniana* appear to be of little real significance.

A monochromatic crustacean such as *Ligia* has only a limited range of color change with dark and pale as its two extremes. In polychromatic forms there may be much wider possibilities; thus *Palaemonetes* may adapt itself with more or less success to backgrounds of white, yellow, red, green, blue, dark gray, and black (Brown, 1935). *Crangon vulgaris* also is capable of extensive adaptation, but lacks the ability to change to green or blue (Koller, 1927). Pouchet (1873) early called attention to a blue pigment in crustaceans which appeared to emanate as a solution from certain chromatophores and to spread in the form of a cloud into the adjacent tissues where it disappeared. This was seen in *Hippolyte* by Gamble and Keeble and has since been identified in *Palaemonetes* (Perkins, 1928), in *Macrobrachium* (Smith, 1930), and in *Portunus* (Abramowitz, 1935c). It is a type of extrachromatophoral pigment as contrasted with the intrachromatophoral colors already alluded to. Both *Crangon* and *Palaemonetes*, as already mentioned, can adapt themselves with more or less success to the color of the environment. *Uca* (Megušur, 1912) on the other hand lacks this ability but shows instead a pronounced diurnal rhythm, being dark by day and pale by night (Abramowitz, 1937a). This type of color change has been known since the days of Gamble and Keeble who recorded it in *Hippolyte,* an observation recently confirmed by Kleinholz and Welsh (1937). It has also been identified in *Idothea* by Piéron (1913, 1914), in *Leander* by Hanström (1937), and in *Ligia* by Kleinholz (1937). These in brief are some of the more striking phenomena concerned with the color changes of crustaceans, changes which in the opinion of investigators prior to 1925 were supposed to be due to peripheral nerve action. This belief that crustacean chromatophores are directly influenced by peripheral nerves was based upon the well-established fact that after the removal of the eyes from a chromatic species color adaptation with all its manifold complications disappeared. But this evidence, though conclusive for the importance of the eye in these reactions, fell short of showing that such chromatophore responses were dependent directly upon peripheral nerves.

The opinion that such responses in crustaceans were neurogenic in origin was persistently held by the older workers notwithstanding the fact that they were unable by the electric stimulation of nerve tracts in these animals (Pouchet, 1872, 1876; Gamble and Keeble, 1900) and by the cutting of their peripheral nerves and their central nervous organs (Pouchet, 1876; Yung, 1878; Mayer, 1879; Matzdorff, 1883; Gamble and Keeble, 1900; Fröhlich, 1910; Menke, 1911; Degner, 1912) to obtain anything but negative results. Tests on nerves were carried out very fully by Koller (1925, 1927) in *Crangon* and especially by Perkins (1928) in *Palaemonetes* with the result that both investigators were forced to conclude that the central nervous organs and the peripheral nerves in these crustaceans were not concerned with chromatophoral responses. The first suggestion of the way in which crustacean chromatophores were controlled came from an observation by Koller (1925) who noted that when the blood of a dark *Crangon* was injected into a pale one kept in light surroundings the pale individual in ten to twenty minutes became dark. On the other hand blood from a pale *Crangon* when introduced into a dark or a pale one had no effect upon the recipient's color. These conditions led Koller to suspect that the chromatic changes in this shrimp were under the control of internal secretions.

Perkins (1928) who, as already noted, had abandoned the idea that the central and peripheral nervous systems in *Palaemonetes* were concerned with this shrimp's color changes, turned to a study of its body fluids and devised a very simple but effective method of temporarily occluding the passage of blood through its dorsal abdominal blood-vessel. When the flow of blood in this vessel in a dark shrimp was stopped and the animal put on a white background, the whole shrimp blanched except that part of the abdomen which was without circulation. This remained dark, but on restoring its blood supply it rapidly became blanched. When a pale individual with an occluded vessel was transferred to a jar with black walls, the animal darkened as a whole except posterior to the point of the stoppage of blood where it remained pale. On releasing the vessel this posterior portion darkened. These observations led Perkins to assume that an active agent concerned with the color changes in *Palaemonetes* was carried in its blood and he proceeded then to look for an organ in this shrimp by which such a substance might be produced. After much search this was found to be the eye-stalks of the animal. When the eye-stalks of a pale *Palaemonetes* were removed, the shrimp darkened and when several of these stalks were crushed in sea-water and extracted and the extract was injected into a blinded shrimp whose chromatophores in consequence were expanded, these color cells contracted. No color changes were seen when similar injections were made into pale *Palaemonetes,* nor did ordinary sea-water, when introduced into this form, bring about any color alteration in either the pale or dark individuals. From these observations Perkins concluded that the eye-stalks of *Palaemonetes* produce a substance, a neurohumor, that induces a contraction of chromatophores. He was unable, however, to find out the means by which this shrimp brought about an expansion of its color cells. Perkins' discovery of the source of the chromatic neurohumor in *Palaemonetes* was quickly confirmed by Koller (1928) in *Crangon,* and in this shrimp Koller believed further that he had located a rostral organ responsible for the expansion of the chromatophores.

Perkins' announcement that an activator of chromatophores was to be found in the crustacean eye-stalk was soon substantiated in a large number of malacostracans, including the stomatopod *Squilla* and the mysids *Praunus* and *Mysis.*[1]

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[1] Active eye-stalk neurohumors have been obtained from representatives of the following genera of brachyuran decapods: *Callinectes* (Perkins and Kropp, 1932; Hanström, 1935, 1937; Carlson, 1936), *Cancer* (Perkins and Kropp, 1932; Kropp and Perkins, 1933; Hanström,

In all these crustaceans an extract of the eye-stalk when injected into another individual of the same or related species induced a color change. The only exceptions to this rule thus far found occur in the anomuran decapods *Hippa* and *Gebia* and in the isopod *Ligia*. Extracts from the eye-stalks of *Hippa* and of *Gebia* were found by Hanström (1935) to be inactive in exciting color changes. The tissue in the heads of these forms and immediately below the base of their eye-stalk was found, however, to induce color changes. Hanström, therefore, concluded that in these two crustaceans the part of animal concerned with the formation of the neurohumor appropriate for color change had shifted from the stalk to a subjacent position, a condition that probably also characterizes *Emerita*, *Gebiopsis*, *Calocaris*, and *Callianassa* (Hanström, 1937). This view was confirmed by Carlson (1936). In the isopod *Ligia* as in all other members of its group the eyes are sessile, the stalk being absent. It is not surprising, therefore, that here as in *Hippa* and *Gebia* the tissue of the head yields a chromatophore activator as was first demonstrated by Kleinholz (1937). Thus in one way or another all chromatic crustaceans whose color changes have been investigated in this respect are known to possess neurohumoral organs, though the locations of these organs are not always the same. It is an interesting fact, pointed out by Kropp and Perkins (1933) that some crustaceans such, for instance, as *Homarus*, *Libinia*, and *Cancer*, which lack obvious integumentary chromatophores, nevertheless possess vigorous eye-stalk neurohumors. This condition was also noted by Hanström (1937) who in discussing the matter was led to conclude that the chromatic neurohumors in these forms may well have other functions than that of regulating color changes. Thus, for instance, they may be concerned with controlling the movement of the retinal pigment, or with the calcium balance in the blood or with other like metabolic activities. It is also to be kept in mind that though the adults of these crustaceans may be devoid of effective color changes, the young may not and that the chromatic neurohumors found in the adults may be merely residues of those whose real importance belongs to an earlier stage.

Since the eye-stalks or adjacent tissues in crustaceans generally produce a chromatic neurohumor, it is natural to inquire what particular organ in or about these stalks is concerned with this function. Koller in 1930 demonstrated that an extract from the cap of the eye-stalk in *Crangon*, namely from that part composed chiefly of retina, was quite inactive as a chromatic agent, but that one from the non-proximal portion of the stalk was fully efficient. These observations were confirmed by Hosoi (1934) in *Penaeus*. By very local cauterization on *Crangon* Koller was led to place this neurohumoral generator near the basement membrane of the retina. Biological tests of different parts of the eye-stalk in *Penaeus* induced Hosoi to conclude that this secretory organ in *Penaeus* was located proximal to the position assigned to it in *Crangon* by Koller, but not so far as the middle of the stalk. More precise localization studies were afterwards carried out by Carlson (1935, 1936) and by Hanström (1935, 1937). Hanström (1934) had pointed out that the crustacean eye-stalk often contained two innervated glandular organs, the X-organ and the blood gland, or as it has subsequently been called, the sinus gland (Hanström, 1937). One or both

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1935, 1937; Carlson, 1936; Abramowitz, 1937), *Libinia* (Perkins and Kropp, 1932; Kropp and Perkins, 1933a; Hanström, 1935; Carlson, 1936; Abramowitz, 1937b), *Carcinus* (Hanström, 1935, 1937; Carlson, 1936; Abramowitz, 1937a), *Ovalipes* (Hanström, 1935, 1937; Carlson, 1936), *Panopaeus* (Hanström, 1935), *Uca* (Carlson, 1935, 1936; Abramowitz, 1936b, 1937b), *Aratus* (Hanström, 1937), *Ocypoda* (Hanström, 1937), *Sesarma* (Hanström, 1937); from representatives of the anomuran genus *Pagurus* (Kropp and Perkins, 1932; Perkins and Kropp, 1933; Hanström, 1935, 1937; Carlson, 1936; Abramowitz, 1937a); from representatives of the macruran genera: *Crangon* (Koller, 1928, 1930; Koller and Meyer, 1930; Perkins and Kropp, 1932; Kropp and Perkins, 1933; Hanström, 1935, 1937; Carlson, 1936; Abramowitz, 1937a 1937b), *Leander* (Koller, 1928; Hanström, 1935, 1937; Kleinholz and Welsh, 1937), *Macrobrachium* (Smith, 1930), *Palaemonetes* (Perkins and Snook, 1931, 1932; Perkins and Kropp, 1932; Brown, 1935; Kropp and Crozier, 1934; Navez and Kropp, 1934; Hanström, 1935, 1937; Carlson, 1936; Abramowitz, 1937a, 1937b), *Homarus* (Perkins and Kropp, 1932; Kropp and Perkins, 1933; Hanström, 1935, 1937; Abramowitz, 1937a), *Pandalus* (Perkins and Kropp, 1932; Kropp and Perkins, 1933), *Palaemon* (Beauvallet and Veil, 1934), *Paratya* (Hosoi, 1934), *Penaeus* (Hosoi, 1934; Hanström, 1937), *Cambarus* (Hanström, 1935, 1937; Carlson, 1936), *Astacus* (Carlson, 1936), *Acanthephyra* (Hanström, 1937), *Hippolyte* (Kleinholz and Welsh, 1937); from representatives of the stomatopod genus *Squilla* (Hanström, 1937); and from representatives of the schizopod genera *Mysis* (Koller and Meyer, 1930; Perkins and Kropp, 1932; Kropp and Perkins, 1933) and *Praunus* (Koller and Meyer, 1930; Hanström, 1937).

of these might be the producer of the chromatic neurohumors. Carlson (1935) cut the long eye-stalks of *Uca* into three equal parts. Of these only the middle one yielded an extract that was chromatically active. If the distal parts of the eye-stalk were cut from a living crab, the animal would maintain its original dark color. If now the middle part was removed, the crab would grow pale as it would after the removal of the entire stalk. Carlson, therefore, concluded that the seat of origin of the chromatic neurohumor in this crab was in the middle third of its eye-stalk. A histological examination of the eye-stalk of *Uca* showed no evidence of an X-organ there, but demonstrated the presence of a well-developed sinus gland in the middle section of the stalk. Hence Carlson (1936) concluded that the sinus gland is in all probability the source of the neurohumor. This conclusion was accepted by Hanström (1935) who also showed that the position of the X-organ and the sinus gland in *Pagurus* likewise pointed to the latter as the source of the chromatic neurohumor. Hanström (1937) further demonstrated that in those crustaceans in which the eye-stalks were more or less reduced, but in which the tissue below them yielded a chromatic neurohumor, as for instance in *Hippa* and *Gebia,* a sinus gland was not to be found in the stalk, but was to be located in the subjacent region. It is, therefore, now generally admitted that the sinus gland, a structure discovered by Hanström, is the source and probably the all important source of the crustacean chromatic neurohumor. Hanström (1935, 1937), however, has called attention to the current belief that there may be several such neurohumors and that it will be well not to dismiss the X-organ completely from the category of possible chromatic glands till more complete evidence is at hand.

Suggestions of other possible sources for chromatic neurohumors in crustaceans have not been wanting. Extracts of the ventral nerve cord of *Palaemonetes* (Brown, 1933) and of *Penaeus* (Hosoi, 1934) were found to be active as excitants of color changes and Hosoi found this also to be true of extracts of the male genitalia, the stomach, and the muscles of *Penaeus,* but not of the heart. All these positive reactions, however, may be due, as Kleinholz remarked (1936a), to traces of the hormone present in the blood and held within the various organs tested. Such records as evidence of additional sources of chromatic neurohumors can scarcely be accepted until this whole subject has been thoroughly reinvestigated.

The question of a rostral organ concerned with the elicitation of the dark phase in crustaceans and particularly in *Crangon* (Koller, 1928, 1930) is still a matter of debate. This organ was described by Koller as situated in the dorsal part of the cephalothorax of *Crangon vulgaris* directly behind the rostral spine. According to Koller's most recent statements (1938) evidence from four sources favor the belief in this part of the shrimp as the seat of an activating organ for the dark phase. If a pale *Crangon* on a white background is fed with pieces of different organs from a dark individual such, for instance, as pieces of stomach, liver, gonads, muscles, eyes, and rostral tissue, the last named is the only one that will excite an expansion of the dark pigment. Extracts of the rostral region when injected into a pale *Crangon* will induce darkening in some twenty minutes, while control injections are without effect. Destruction of the rostral region leaves the shrimp unable to darken. Finally pressure on the rostral region of a pale shrimp is followed in four minutes or so by darkening. These observations confirm Koller in the belief that the rostral region of this shrimp contains tissue active in producing a darkening neurohumor. Other investigators have not been able to demonstrate a dispersing chromatic organ in the rostral regions of the crustaceans studied by them. Thus Perkins and Snook (1931) state that all their attempts to expand the chromatophores of *Palaemonetes* by injecting rostral extracts from this shrimp met with failure and a similar report is made by Brown (1935) who also worked on *Palaemonetes.* Kropp and Perkins (1933) likewise obtained negative results from their tests of the American shrimp *Crangon boreas.* In no instance could they obtain a chromatophore-expanding action following an injection of rostral extract into a pale *Crangon* though care was taken to prepare the material from the region designated by Koller and in the manner prescribed by him. Beauvallet and Veil (1934) working on *Palaemon* found that rostral extracts from this shrimp would turn pale individuals dark. This change, however, was only an occasional happening and occurred only when very concentrated solutions were used. Since Koller's results have not been confirmed on *Palaemonetes* or on *Crangon boreas,* it may be that the possession of a rostral organ is, so far as present knowledge is concerned, a peculiarity of *Crangon vulgaris.* The solution of this difficulty must await further investigation.

It must be evident from what has been stated that of the various suggested sources for the chromatic neurohumors in crustaceans the only certain one is the sinus gland in or near the eye-stalk. How many neurohumors are produced by this or other possible glands and what they are like chemically are questions which for the present are beyond answer. At best only approximate intimations can be offered. The first neurohumoral extract to be identified was that obtained by Perkins (1928) from the eye-stalks of *Palaemonetes.* This had the general property of blanching *Palaemonetes* by concentrating its dark chromatophoral pigment. Perkins was unable to find any other neurohumor in this crustacean. Koller (1928), as just stated, believed that *Crangon* possessed in addition to this a rostral-dispersing humor, but the uncertainty of this view must be evident. Admitting its correctness, however, *Crangon* could then be said to possess at least two neurohumors. To these Koller gave the names of expantin and contractin. He also advanced reasons for assuming another neurohumor in *Crangon* for the dispersion of yellow. He thus raised the total number of chromatic neurohumors in this shrimp to three (Koller, 1938). Brown (1935) who studied the responses to different backgrounds of the four pigments in the chromatophores of *Palaemonetes* adduced evidence to show that these pigments were capable of complete independence in their activities. To determine this it was necessary to observe simultaneously two pigments as the shrimp was treated experimentally and to find situations in which these pigments were able side by side in the same animal to show all possible combinations of behavior in migration. A sample of this kind of treatment is given in Table I which is taken from Brown paper of 1935.

As an example of this kind of treatment the independence of the responses of the red and the yellow pigments may be considered. This is shown in column A of the table where are indicated the various background responses which when taken collectively demonstrate the independence of the red and yellow colors. Thus on white both these are concentrated, on red the red pigment is concentrated, and the yellow dispersed, on dark gray red is dispersed and yellow concentrated, and on black both are dispersed. By evidence of this kind Brown was led to declare that all four pigments in *Palaemonetes* were capable of independent response and to assert that no fewer than four neurohumors must be assumed for the various chromatic changes in this shrimp. It was Brown's opinion that in these changes *concentration was a humoral response and dis*persion an activity due to the chromatophore itself without aid from a neurohumor. Such views as those put forward by Koller and by Brown in which more than one neurohumor is involved have been brought together by Abramowitz (1937b) under the general head of the multiple theory of chromatophoral action as contrasted with what he has called the unitary theory of these activities in which, as will be explained presently, only one neurohumor is involved.

It was established by Perkins (1928) in the early period of the study of crustacean neurohu-

TABLE I

Tabular representation of the condition of the four pigments in animals upon colored backgrounds. In vertical column A are checked those backgrounds which, taken together illustrate that the red and yellow pigments behave independently of one another. Column B does the same for the combination of red and white pigments; C for the yellow and white; D for the yellow and blue; E for the red and blue; and F for the blue and white. (*Brown, 1935*)

Background color	Condition of red pigment	Condition of yellow pigment	Condition of white pigment	Blue net-work	A	B	C	D	E	F
White	Conc.	Conc.	Disp.	Absent	X	X	X	X	X	X
Green	Conc.	Conc.	Disp.	Present						X
Red (1)	Conc.	Disp.	Disp.	Absent	X		X	X		
Red (2)	Disp.	Disp.	Disp.	Absent		X			X	
Blue	Conc.	Conc.	Conc.	Present		X	X	X	X	
Dark gray	Disp.	Conc.	Conc.	Present	X					
Black	Disp.	Disp.	Conc.	Present	X	X	X	X	X	X
Darkness	......	......	Conc.	Absent						X

mors that when the eye-stalks are cut off from *Palaemonetes*, the shrimp darkens. It was also shown by Perkins that when into such a darkened individual an extract of its eye-stalk is injected, the shrimp will blanch temporarily. Carlson (1935) was the first to point out that the reverse of this was true of the crab *Uca*. If its eye-stalks are removed, it blanches instead of darkens, as in fact Megušar (1912) had long ago shown. If now an extract of its eye-stalks is injected into a stalkless and consequently pale *Uca*, the latter darkens. Thus *Uca* reacts both to the loss of its eye-stalks and to their extract in the opposite way that *Palaemonetes* does to a similar loss and to its own eye-stalk extract. These remarkable conditions were fully discussed and further illustrated in 1936 by Carlson who also pointed out the following additional peculiarity. When the eye-stalk extract from *Uca* is injected into another *Uca*, stalkless and consequently pale, the recipient, as already mentioned, darkens. When such an *Uca* extract is injected into a stalkless and consequently dark *Palaemonetes*, this shrimp blanches. Here then the same extract which darkens a stalkless *Uca* blanches a stalkless *Palaemonetes*. These very interesting observations were fully confirmed and somewhat extended by Abramowitz (1937b) who was led to remark that such results "show that an extract of the eye-stalks, regardless of its source, produces the same qualitative chromatophoral responses in a particular species as those induced by injection of the species' own stalk extract. This obviously means that either there is present in the eye-stalks of every crustacean investigated one pigmentary hormone whose effects are determined by the particular chromatophoral organization of the species into which it is injected, or that each crustacean contains in its eye-stalks a veritable array of hormones, one for but one of the two phases of a particular pigment, so that depending upon the species injected, a certain pigment may be now contracted, now expanded." These new discoveries appear to brush aside at once, as Abramowitz remarks, Koller's proposed types of neurohumors, expantin and contractin, for a single extract, and presumably a single neurohumor, acts on one crustacean as a dispersing agent and on another as a concentrating one. These observations also set the whole question of the number of chromatic neurohumors in crustaceans in a new light and call for a radical reinvestigation of the whole field.

Abramowitz (1937b) who has discussed this question with much fullness is of opinion that either there are numerous specialized hormones acting upon the body of chromatophores (multiple theory) or one hormone to which there are different types of chromatic response in accordance with chromatophoral organization (unitary theory). According to Abramowitz the present body of observations in this field may be interpreted on the basis of either conception. He states, however, that if Brown's tabulated observations are correct, it "is almost inescapable that there must be more than one hormone." And he adds that "future studies may well reveal that many or at least more than one hormone are secreted by the eye-stalk" though, as he remarks, this view is not supported by present evidence.

From what is now known of the reactions of chromatophores in crustaceans, it would be rash indeed to attempt any prediction as to the number of neurohumors. Their one certain source, the sinus gland, is so simple in structure that it seems to favor the unitary theory, but there are other possible glands, as Hanström has remarked, that must not be forgotten. Furthermore, the sinus gland may not be so simple in organization as at first sight it appears to be. It is also possible that a single neurohumor may act differently at different concentration as suggested by Przibram (1932) and thus play more than one part. That chromatophores are different in organization, as has been insisted upon by Abramowitz (1937 b), is beyond cavil. Even within a single category, such for instance as melanophores, diversity reigns. Adrenalin, which is the only chromatic neurohumor whose chemical purity can be assured is well known to disperse pigment in retinal melanophores as, for instance, in the frog, and to concentrate it in the melanophores of this animal's skin. Even in the integument the menalophores in one spot react to the same reagent differently from what they do in another. It must also be kept in mind that the individual chromatophore probably changes in its receptiveness to exciting agents from moment to moment. A melanophore after dispersing its pigment may not be the same as it was when its pigment was concentrated. The mere operations of concentrating and dispersing pigments may change the cell. Hence it is not inconceivable that the same agent may find a different type of reception in a color-cell with expanded pigment from what it does in the same cell with contracted pigment. These suggestions favor for the most part the unitary theory, but the opposing view, the multiple theory, is not without support. First of all it must not be forgotten that the multiple theory does not necessarily require such a large array of neurohumors as has been suggested, for instance, by Abramowitz (1937b). In fact it is possible that the four neurohumors hypothesized by Brown for *Palaemonetes* may not all be needed. It is conceivable that by appropriate combinations fewer elementary neurohumors may suffice. Thus if in a purely formal way three basic neurohumors A, B, and C are assumed, there may be made from these the additional combinations AB, AC, BC, and ABC which with the original A, B, and C give a total of seven agents. Such a condition could obtain, of course, only provided each combination is in some sense a combined product and not merely elements mixed. Relations of such a kind, however, would be by no means surprising when the complexity of organic interactions is kept in mind. In this way a final complexity of agents might rest on a relatively simple base and the so-called unitary and multiple theories might thus be brought more nearly together. These two views as already formulated are perhaps somewhat too rigid and inelastic to meet the exigencies of a situation whose difficulties call for experimental solution. They possess an obviousness and a clearness which in a measure carries with it their own fate, for the unitary theory must be discarded on the discovery of two neurohumors. The real question involved is not whether there is one or more neurohumors, but what the exact number is. However, till a chemical clarification of the state of the eye-stalk extract is made, it is futile, as Abramowitz remarks, to speculate on the exact number of its neurohumors. Most workers have placed this approximately at several (Hanström, 1938).

If little can be affirmed as to the number of crustacean neurohumors still less can be said of their chemical nature. That the neurohumor in *Palaemonetes* is soluble in water (hydrohumor) was demonstrated by Perkins (1928) in his initial experiments. That it is not destroyed by boiling or drying was recorded by Perkins and Snook (1931), whose observations in this respect have been confirmed by many subsequent workers. In fact it has been shown that boiled extract is often more effective than unboiled (Carlson, 1936). Carlson (1936) found that the neurohumor in *Palaemonetes* would diffuse through a cellophane membrane, that it was not soluble in ether, but could be dissolved in alcohol and that it was not destroyed by being boiled in either weak acid or weak alkali. The eye-stalk neurohumor from *Uca* was stated by Abramowitz (1937a) to be readily soluble in water, not completely soluble in ethanol or methanol, only slightly soluble in acetone, and insoluble in benzine, chloroform, or ether. It does not decompose when boiled with weak acid or alkali for a short time, but does break down completely after being boiled for two hours in weak alkali. It is thermostable and not destroyed by drying. It can be kept in an aqueous solution in a refrigerator for some time without loss of activity, but in water and at room temperature it slowly disappears. Little more can be said of the chemical nature of these bodies; the facts thus far contributed show with reasonable certainty that they are not typical proteins, but their exact chemical nature is at present quite obscure.

From what has been stated in this survey of the activation of crustacean chromatophores, it is clear that the the old view of direct nervous stimulation of these color cells must be completely abandoned. The crustacean eye and its central nervous connections are means of controlling the secretions of the sinus gland and other like structures. Thus far the operation is nervous, but the neurohumor produced in this way is carried by the blood to the distantly located chromatophore which is strictly a hormonal or humoral procedure. This second step in the operation is much the more considerable from the standpoint of space covered and yet it was entirely overlooked by the older workers. Thus the real stimulation of chromatophores in crustaceans is a purely neurohumoral affair carried out by a hydro- or water-soluble humor. It lacks all traces of direct nervous action.

III. VERTEBRATE NEUROHUMORS

1. *Introduction*

The interpretation of the control of vertebrate chromatophores was in the beginning strictly nervous like that for the color cells in crustaceans. This view of nervous activation was subjected to experimental test and was fully discussed as long ago as 1852 by Brücke in his account of the color changes in the chameleon. It was accepted in detail by Lister in his admirable essay on the chromatic reactions of the common frog published in 1858. It was the main thesis of Pouchet's brilliant memoir on the chromatophores of fishes issued in 1876. The demonstration by histological means of the nerve endings on the melanophores in teleosts made simultaneously by Ballowitz (1893) and by Eberth (1893) seemed to be the final link in the chain of evidence in its favor. It permeated completely von Frisch's scholarly contributions to the study of teleost coloration (1910, 1911a, 1911b, 1912a, 1912b). It was the only view admitted by Biedermann in his exhaustive treatment of the color changes in frogs (1892). A survey of the many papers dealing with this field from the standpoint of those just mentioned leaves the impression that the system of vertebrate chromatophores, like that of their muscles, is composed of effectors activated exclusively by nerves.

In most of the later contributions to this subject which favored the neurogenic conception of chromatophore activation, there was no consideration whatever of a growing opinion that the activation of chromatophores might be due, in part at least, to the special hormones known as neurohumors rather than to nerves. This opinion was first suggested by the work of certain experimental embryologists. Some two decades ago Smith (1916a, 1916b) and Allen (1916, 1917) showed independently that frog tadpoles, which had been deprived previously of the rudiments of their pituitary glands, became pale and remained so indefinitely. The importance of the pituitary gland in this respect was confirmed subsequently by Atwell (1921), Giusti and Houssay (1921), Swingle (1921), Krogh (1922) and a number of others, but particularly by Hogben and his associates who in a series of highly original contributions beginning in 1922 carried the whole subject forward with great success. In particular Hogben and Winton (1922a, 1922b, 1922c, 1923) showed that in the common frog cutting or stimulating its sciatic nerve was not followed by color changes in the skin of the leg tested. They confirmed the observations of earlier workers that the loss by the frog of its pituitary gland was invariably followed by blanching which could be temporarily changed to darkening by an injection of extract from the pituitary gland of another frog or of almost any other vertebrate. The darkening of a pale, hypophysectomized frog could also be induced by the implantation into its body of a fresh pituitary gland. Thus Hogben and Winton (1923) were led to conclude that the nervous factor in the control of the color changes of the frog was at best insignificant and that these changes were due primarily to fluctuations in the amount of pituitary secretion liberated within the animal. The momentary coloration of a given frog was in their opinion an index to its own pituitary activity. After a general survey of the field of integumentary color activation in the vertebrates, Hogben (1924b) concluded that there must be striking differences in the chromatophore systems of these animals, for the color cells of fishes and of reptiles appeared to be under nerve control while those of amphibians were activated by hormones. Such a conclusion, though warranted by the facts as then known was not wholly satisfactory from a zoological standpoint, for it would be strange indeed if fishes and reptiles, two groups well separated systematically, should exhibit a common type of chromatophore activation differing fundamentally from that of the intermediate group, the amphibians. It seemed, therefore, desirable to undertake a restudy of the means of excitation of color changes in a number of chromatic vertebrates and thus to ascertain how considerable their differences really were. To this end the common frog, certain dogfishes, *Mustelus* and *Acanthias*, certain teleosts, *Fundulus* and *Ameiurus*, as well as the western lizard *Phrynosoma*, were made the objects of special investigation.

2. *Amphibians*

In the earliest account of the color changes in frogs (Vallisnieri, 1715), these changes, according to van Rynberk (1906), were attributed to the nervous system. This opinion has been held by a long line of exceptional investigators reaching down almost to the present day (Lister, 1854; Bimmermann, 1878; Biedermann, 1892, 1926; Kahn, 1922; Perotti, 1928). To any one familiar with the results of nerve cutting in frogs and in bony fishes no contrast could be sharper. The absence of changes in tints of the skin on cutting cutaneous nerves or more deep-seated autonomic trunks is as characteristic of frogs as its presence is of teleosts. So universal is the absence of color change on cutting, stimulating, or otherwise treating integumentary nerves in frogs, toads, and related forms that one is forced to accept the general conclusion of Hogben and his associates (Hogben and Winton, 1922–1923) that the nerves in these vertebrates are without significance for color changes. Such changes appear to be brought about exclusively by endocrine agencies. So fully supported is this conclusion that the real question today is not nerves versus endocrines or better neurohumors, but which and how many neurohumors are involved in the chromatophore responses of these animals.

That the dark phase of amphibians is due to a substance from the intermediate lobe of the pituitary gland called by Hogben and Slome (1931) B-substance and by Zondek and Krohn (1932a) intermedin, has been supported by the work of a host of investigators (Smith, 1920; Allen, 1930; Atwell, 1921, 1935, 1937; Giusti and Houssay, 1921; Swingle, 1921; Krogh, 1922; Hogben and Winton, 1922a, 1922b, 1922c, 1923; Hogben, 1924a, 1924b, 1926; Fenn, 1924; Houssay and Giusti, 1929; Charles, 1931; Zieski, 1932; Burns, 1934; Aubrun, 1935a, 1935b; Jores and Caesar, 1935; Abramowitz, 1936b; Osborn, 1936; Atwell and Holley, 1936; Parker and Scatterty, 1937; and many others) and is now generally conceded. There is not the least doubt at present that the single neurohumor, intermedin, is responsible for the dark phase of frogs and probably all other amphibians.

The pale phase of the frog was attributed by Hogben and Winton originally to the disappearance from the animal's blood of the dispersing neurohumor, their B-substance. Hogben, however, and another of his associates, Slome, after an extended study of the color changes in the South African toad *Xenopus,* were led to conclude (Slome and Hogben, 1928, 1929; Hogben and Slome, 1931, 1936) that in addition to intermedin there was in this toad also a concentrating neurohumor actively concerned with the blanching of this form. The chief evidence for this opinion was found in the fact that when the pituitary gland was removed from this toad, it failed to blanch as completely as it did when with its pituitary gland intact it was exposed to a white illuminated environment. The more complete blanching when the gland was still in place indicated, in the opinion of these workers, the production by the toad of a second substance, their W-substance, whose effectiveness was lost with the loss of the gland. The part of the pituitary complex believed by these authors to be the seat of the formation of the W-substance was the pars tuberalis not only in *Xenopus* but also in *Rana fascigula.*

The production of W-substance in the American frog *Rana pipiens* was investigated by Parker and Scatterty (1937). This frog becomes fully blanched after an injection of a small amount of adrenalin, after its blood-vessels have been thoroughly irrigated with Ringer's solution, or after hypophysectomy. The melanophores in such blanched frogs are fully punctate and could not concentrate their pigment further. That they are still normally responsive to chromatic excitants can be shown by injecting a solution of intermedin into such pale frogs whereupon their color cells soon disperse pigment and the frog as a whole darkens. These pale frogs are as a rule slightly paler than normal frogs that have been kept in a white-walled, illuminated vessel. In this respect they are unlike *Xenopus* and they thus fail to yield any evidence in favor of the presence of W-substance. This conclusion is supported by the observation that though blood serum from a dark Rana pipiens when injected into a pale one will darken it, that from a pale one has no influence on the color of a dark individual of the same species.

The conclusion to be drawn from this investigation is that the control of the melanophores in *Rana pipiens* appears to be like that originally ascribed by Hogben to amphibians in general, a pituitary dispersing agent whose absence from the blood allows the melanophores to concentrate their pigment. From this standpoint *Rana pipiens* may be said to be unihumoral as contrasted with *Xenopus* where the conditions appear to be those of a bihumoral animal.

In this connection the condition of frogs blinded by enucleation is not without interest. A frog blinded by the loss of its eyes soon assumes a constant relatively dark tint, but one that is not so dark as that of full pigment dispersion (Parker, Brown, and Odiorne, 1935). It is difficult to explain this state from the neurohumal position except on the assumption of a steady, low discharge of intermedin. Such a discharge apparently goes on whether the blinded frog is in the dark or in the light, but it is not uniform under these two conditions. In the light the frog is a little darker than in darkness, conditions that imply that some organ in its body other than the eye must exert a mild control over the discharge of intermedin, or that the melanophores respond directly to light or its absence.

Amphibians such as *Rana pipiens* are not the only unihumoral vertebrates known. Within recent years two others have been described, namely *Lampetra* among the cyclostomes and *Anolis* among the lizards. *Lampetra,* whose color changes have been studied by Young (1935) is provided on the upper part of its body by melanophores of the usual vertebrate type. Below it is uniformly pale. When individuals were placed in white or black illuminated receptacles no differences could be detected, for in both situations the lampreys remained maximally dark. On further examination, however, they were found to have a pronounced daily rhythm in color change, becoming pale by night and dark by day. Continuous artificial illumination produced maximal darkening and stopped the daily rhythm, but total darkness allowed the rhythm to persist though diminished in extent. The cutting of spinal nerves was not followed by local changes in the melanophores and it was rightly concluded by Young that these effectors were not under nervous control. The removal of the pituitary complex by a buccal operation or the destruction of its nervous and intermediate lobes reduced the lamprey to a condition of continuous paleness which could be changed temporarily to the dark state only by the injection of mammalian or other vertebrate intermedin. The paleness induced by the loss of the pituitary complex persisted in a lamprey that lived as long as eleven months after the operation. A thorough test of *Lampetra* revealed to Young no means of blanching in this animal except the loss from its blood of the darkening pituitary secretion. He therefore concluded that the color changes in *Lampetra* were dependent entirely upon one neurohumor from the pituitary gland and that the presence or absence of this neurohumor was determined by nervous action. Thus *Lampetra,* like *Rana pipiens,* appears to be a good example of a chromatic vertebrate whose color changes are on a unihumoral basis.

Another example of a chromatic vertebrate with a limited number of neurohumors is the American iguanid *Anolis carolinensis.* The color reactions of this lizard have been studied recently by Kleinholz (1936). On a white illuminated background *Anolis* becomes bright green, on a black one dark brown. In darkness it takes on the green tint. According to Carlton (1903) and von Geldern (1921) the only active chromatophores in the skin of this lizard are the melanophores. It was assumed by these earlier workers and even as late as 1924 by May that these color cells were under direct nervous control. May based his opinion on experimental results from the transplantation of chromatic skin. According to him a piece of skin transplanted from one *Anolis* to another remained green for some two to three weeks. After this period it began to regain its power to change and soon acted in unison with the rest of the animal in its chromatic alterations. This recovery was believed by May and others to be the result of nerve regeneration. Kleinholz demonstrated, however, that in transplants made on the same animal, autotransplants, color changes could be detected on the second or third day after the operation and that when a transplant was made from a hypophysectomized donor to a normal recipient and well fitted to the recipient's body, color changes excited by background differences could be seen in the graft within twelve hours. These changes lagged only a little behind the corresponding ones in the normal skin of the recipient. Such intervals of time as those pointed out by Kleinholz are much too brief to allow of nerve regeneration as an explanation of recovery and they led Kleinholz to suspect that this chromatic recovery was to be associated with renewed vascular connections rather than with nervous changes. Loss of the hypophysis was always followed by permanent pallor (green) which could be temporarily converted into the dark phase (brown) by the injection of pituitary extract. Denervated patches of skin underwent these changes. Electrical stimulation of the mouth of a normal *Anolis* evoked darkening, a color change which failed to appear where this type of stimulation was applied to the same part of a hypophysectomized individual. Hence this form of stimulation is believed to affect the pituitary gland. No special means was discovered by Kleinholz whereby *Anolis* blanched and he finally concluded that this operation (turning green) was due to the disappearance from the circulation of the pituitary intermedin. Thus the ordinary dark (brown) and pale (green) phases of this lizard were shown to be not directly concerned with nerves, but to be dependent upon the presence or absence of a single pituitary neurohumor. Thus so far as its chief color changes are concerned, *Anolis* is unihumoral. Kleinholz, however, also found in the color pattern of this animal a mottled state which he showed was not dependent upon nerves, but which could be excited by the injection of adrenalin and disappeared on the loss of the adrenal glands. Thus an additional neurohumor must be admitted to the chromatic system of *Anolis,* but this element is not necessarily concerned with the ordinary dark and pale changes of this lizard which, as just pointed out, appear to be on a unihumoral basis. Thus *Rana pipiens, Lampetra planeri,* and *Anolis carolinensis,* so far as their ordinary pale and dark changes are concerned, seem to be unihumoral. *Anolis,* however, shows evidence of beginning bihumoralism which is apparently true of *Xenopus.* In all these instances direct nerve action is excluded and the color changes in these three forms depend strictly upon hydrohumors.

3. *Elasmobranch Fishes*

The serious study of the color changes in elasmobranchs began with the work of Lundstrom and Bard (1932) on the smooth dogfish *Mustelus canis.* This fish has well pronounced pale and dark phases dependent upon melanophore activity. When its pituitary gland is removed it becomes permanently pale, as was first shown by Lundstrom and Bard and subsequently confirmed by Parker and Porter (1934). All other elasmobranchs that have been tested in this way show the same peculiarity (*Squalus acanthias*, Parker, 1936a; *Scyllium canicula, S. catulus, Rhina squatina, Raja brachiura, R. clavata, R. maculata, R. microcelatus;* Hogben, 1936; Wykes, 1936; Waring, 1936a, 1936b). An injection of an extract from the pituitary gland into such pale elasmobranchs is always followed by a darkening of their integument. No other organ than the pituitary gland is known to be connected thus with the dark phase of these fishes. If the blood of a dark *Squalus* is injected into a slightly pale one, a dark spot is produced though such blood has no effect on a dark fish. Blood from a pale fish induces no color change when injected into either a dark or a pale individual (Parker, 1936a). What is true of the blood of *Squalus* appears also to be true of that of *Mustelus* (Parker and Porter, 1934). These and other like observations have convinced most investigators that the dark phase of elasmobranchs is excited by a neurohumor produced in the pituitary gland and carried thence by the blood to the responding melanophores.

The pale phase of *Mustelus* was not closely investigated by Lundstrom and Bard (1932) who merely intimated that it was probably due to the absence from the blood of this fish of the dispersing substance intermedin. Parker and Porter (1934) showed, however, that when radiating nerves in the pectoral fin of *Mustelus* were cut, a pale band formed over the denervated area and reached from the cut to the edge of the fin. The initiating cut naturally interfered more or less with the circulation of blood in the part of the fin concerned, but this interference was distinctly local, for, as could be seen under the microscope, it was limited to that part of the band near the cut, the peripheral portion retaining what appeared to be a fully normal blood supply. Hence Hogben's suggestion that such bands are the direct result of vasomotor disturbances fails to apply. Moreover such bands may be excited by the electrical stimulation of nerves without any interference whatever with blood vessels (Parker, 1935a, 1936b). Furthermore when the blood supply to a fin is at a complete standstill in consequence of placing a tourniquet around the base of the fin, a band may still be produced by cutting the nerves (Parker, 1938c). A pale band in a dark fish will in time darken and after it has darkened, it may be revived by recutting the nerves distal to where they were first cut (Parker, 1936b) thus demonstrating that blanching in *Mustelus* is not due to the loss of pituitary secretion, to vasomotor changes, paralysis or the blocking of central impulses, but to the excitation at the cut itself of concentrating nerve fibers which then act directly on the melanophores.

Although pale bands or patches can be produced with great certainty in *Mustelus* by cutting its integumentary nerves, these bands have not been excited in other elasmobranchs subjected to appropriate cuts. In *Squalus acanthias* the cutting of nerves is only rarely followed by the formation of a pale band or a patch and when such areas are produced they are always very faint. In *Raja erinacea* such bands cannot be excited at all and the same seems to be true of *Scyllium* (Young, 1933; Waring, 1936; Wykes, 1936) and of *Raja brachyura* and *R. maculata* (Wykes, 1936). The electrical stimulation of nerves was found by Wykes (1936) to be followed by no color changes in *Raja brachyura, Rhina squatina*, and *Scyllium catulus.* Thus it appears that, so far as is known at present, the formation of well defined, pale bands and patches by nerve cutting is a peculiarity of *Mustelus.*

If *Mustelus* blanches through the action of concentrating chromatic nerves which appear to be absent from other elasmobranchs, how is blanching accomplished in such other forms? In answer to this question two suggestions have been made. Elasmobranchs without concentrating fibers become pale either through the disappearance from their blood of the dispersing pituitary neurohumor already shown to be there under certain circumstances, or they blanch in consequence of the production in their bodies of a concentrating neurohumor such as the W-substance of Hogben.

Hogben (1936) sought for this substance in *Scyllium canicula, S. catulus*, and *Raja brachyura* whose anterior pituitary lobes were suspected of containing it. When this lobe is removed from a dark fish no color change was noted. When it was taken out of a pale fish, the animal became dark even on a white background, as Waring

(1936) also observed. Implantation of an anterior lobe into a pale fish produced negative or relatively slight results. Implantation of such a lobe into a dark fish produced so uncertain a change as to be quite inconclusive. After the removal of the anterior lobe from *Mustelus,* the fish continued to change color normally. But this ability may have depended in part at least on the concentrating nerve-fibers possessed by this dogfish. In *Raja erinacea,* where there are no such nerve-fibers, the loss of the pituitary gland is followed by maximum pallor showing that this gland is not necessary for this extreme reaction. Blood transfers from pale fishes, *Mustelus* (Parker and Porter, 1934) and *Squalus* (1936a), to dark ones produced neither pale spots nor any general change of tint on the part of the recipients. The same was found to be true of transfers of blood carried out on *Raja erinacea* (Parker, 1937b). Thus several elasmobranchs, but especially *Raja erinacea,* give no evidence of a W-substance. Whether further tests will show the presence of this material in those forms from which Hogben and Waring removed the anterior pituitary lobe and thus abolished blanching remains to be determined.

Is it possible that the elasmobranchs other than *Mustelus* blanch by the disappearance of intermedin from their blood? In the elasmobranchs studied by Wykes (1936) *Raja, Rhina,* and *Scyllium,* no special tests such as blood transfers were made and consequently no opinion can be formed as to what may be contained in their blood. In *Raja erinacea* the case is different. This fish has been shown to have no concentrating nerve-fibers and its blood when appropriately transferred gives no evidence of containing a concentrating neurohumor. Its only way of blanching seems to be by the loss of the dispersing pituitary neurohumor from its blood. Thus the elasmobranchs in last analysis present a variety of conditions in their chromatophoral system. All, so far as is known, darken under the action of the dispersing pituitary secretion, intermedin. *Raja erinacea* appears to blanch in consequence of the loss of this substance and may therefore be regarded as unihumoral. *Scyllium canicula, S. catulus* and *Raja brachyura* may become pale because of a concentrating neurohumor, the W-substance of Hogben, and may therefore be designated as bihumoral species. *Mustelus* appears to be the only elasmobranch thus far known that blanches regularly in consequence of the action of concentrating nerve-fibers.

It is a remarkable fact that the chromatophoral system of the horned toad, *Phrynosoma,* as worked out recently (Parker, 1938a), shows a decided resemblance to that of *Mustelus.* In this reptile the dark phase is dependent primarily upon intermedin and the pale one chiefly upon concentrating nerve-fibers, though these appear to be supplemented in *Phrynosoma* by a hydrohumor, probably adrenalin, of which there is apparently no trace in *Mustelus.*

4. Teleost Fishes

A. *Fundulus heteroclitus* is a small cyprinodont fish from the coastal waters of the Eastern United States. It possesses at least three kinds of chromatophores: melanophores often associated with iridocytes (Foster, 1937), xanthophores, and guanophores (Odiorne, 1933). It may assume a variety of color phases (Connolly, 1925); of these the most conspicuous ranges from a pearly white to a dark steel-gray and depends chiefly upon the melanophores. At 18° to 19° C. *Fundulus,* when transferred from an illuminated white bowl to a black one in full light will darken in a little less than a minute and when transferred in the reverse direction will blanch in somewhat over two minutes (Parker and Brower, 1937). How these responses are accomplished will now be considered.

Since the days of Brücke (1852) it has been known that when a faradic current is applied to the chromatophore tracts or nerves in many vertebrates, these animals blanch through the concentration of pigment in their melanophores. This response is eminently true of *Fundulus.* When such a current is led through the medulla of a dark *Fundulus,* the whole fish quickly loses its deep tint. A similar test on a pale individual is followed by no color change whatsoever. If the current is made to impinge on a bundle of nerves in the tail of a dark *Fundulus,* a pale band is formed from the region of application of the electrodes to the edge of the fin. If a bundle of nerves is cut in the tail of a moderately dark *Fundulus* whereby a still darker band of denervated tissue is produced, the application of a stimulating current to the medulla of the fish will induce its complete blanching except for the denervated band. These and other like tests have long since shown that the pale phase of *Fundulus,* like that in a number of the other lower vertebrates, is under the direct control of concentrating autonomic nerve-fibers, a conclusion that, in its general application, has been admitted by almost all workers in this field (Brücke, 1852; Sand, 1935; Parker, 1938a).

The dark phase of *Fundulus* is not so easily dealt with. It may be induced in all probability both by dispersing nerve-fibers and by a neurohumor such as the intermedin from the pituitary gland. When a small transverse cut is made in the root of the tail of a pale *Fundulus* so as to sever a few caudal nerves, a dark band begins to appear in about half a minute and will soon be seen to reach from the cut to the edge of the tail (Fig. 1). After five minutes this band will be found to be very dark in consequence of the extreme dispersion of pigment in its melanophores. Such bands or dark areas of one form or another have been known for a long time in, for instance, the chameleon and a great variety of teleosts. They have been interpreted as due to the paralysis of the cut nerve-fibers and the consequent lapse of the melanophores into a resting state of expansion. Such a view was held by Brücke (1852) and has been accepted in the main by most investigators down to the present time (Sand, 1935). It may be designated as the paralysis hypothesis of chromatophore reaction (Parker, 1936c).

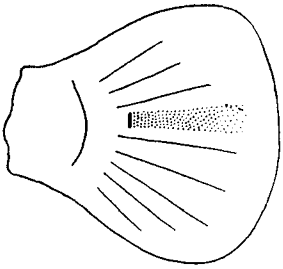

FIGURE 1. Caudal fin of a pale *Fundulus* showing a band of dark melanophores produced by the severance of radial nerves near the root of the tail. Parker, 1934 f, p. 307.

That this hypothesis is probably incorrect can be shown by a simple experiment on *Fundulus*. A dark caudal band produced in the tail of a pale *Fundulus* (Fig. 1) in the way already described will reach its maximum of coloration in a fraction of an hour or so after which it will begin to fade until in the course of a day or two it will have attained to about the same degree of paleness as that of the rest of the fish. If now a second transverse cut is made slightly distal to the first one, and within the limits of the original band, a second dark band will quickly appear and occupy much of the space originally taken up by the first band (Fig. 2). The production of a second band points to two very significant conclusions. It shows, first, that when chromatophore nerve-fibers are cut they are not at once paralyzed, as had generally been assumed, but that they are capable of renewed activity as judged by the pigment dispersion in the melanophores of the second band. It also shows that the formation of such bands is not dependent upon the interruption of central influences, such as tonic or inhibitory impulses, as has recently been suggested by Zoond and Eyre (1934), Zoond and Bokenbam (1935), and Sand (1935), for all such impulses are eliminated by the first cut. The fact that a second cut can be formed shows that this band is produced by some disturbance in the cut itself and not by an agent from a region proximal to the first cut. What the effective disturbance is that gives rise to second bands is not known. That it is not due to the rubbing together of the raw faces of the wound is certain, for a band will form from the distal border of a window cut in the tail where the wound faces cannot possibly rub one another (Fig. 3). Presumably the stimu-

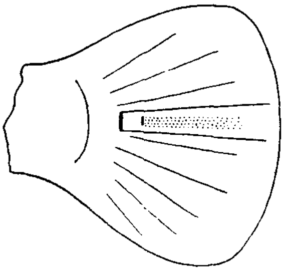

FIGURE 2. A faded caudal band in a pale *Fundulus* within which a new short cut has been made. This cut has induced the formation of a small new band within the large one showing that the severed nerve-fibres of the larger band are still active. Parker, 1934 f, p. 308.

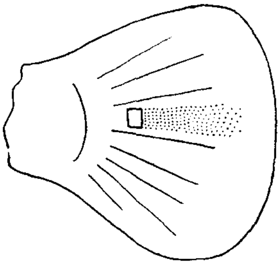

FIGURE 3. A caudal band in a pale *Fundulus* produced by cutting a window-like opening in the tail instead of making merely a slit. Parker, 1934 f, p. 308.

lus for band formation is the action of disintegration products in the cut on the ends of the severed nerve-fibers on the distal face of the cut. But however this may be, the formation of the second band renders highly improbable any hypothesis that has been proposed to account for the formation of caudal bands on the ground of paralysis or the interruption of central impulses.

That the formation of what may be called primary and secondary caudal bands in *Fundulus* as described in the preceding paragraphs is not complicated by the degeneration or regeneration of the melanophore nerve-fibers is seen from the fact that the changes in bands here considered may all occur within the three or four days immediately following the first severance of the chromatophore nerves, whereas degeneration in these nerves is known not to be physiologically significant till five or six days after that time. Regeneration of these fibers begins on about the eighteenth day after the initiation of a primary band and is completed over the whole length of the band on approximately the twenty-fifth day subsequent to the first cut (Parker and Brower, 1933).

That intermedin from the pituitary gland of the fish does not play a necessary part in the formation of the secondary band is evident, for the denervated area on which this band is formed may be fully blanched before the new band is initiated, a condition which would not occur if a physiologically significant amount of intermedin were present in the blood of the pale fish.

If the formation of caudal bands in *Fundulus* is not dependent upon the paralysis of chromatophore nerve-fibers, upon the obstruction of tonic or inhibitory central impulses, upon degeneration or regeneration of nerves, or upon the presence of small amounts of intermedin in the blood, what is it dependent upon? A most likely answer to this question is that the melanophores in such bands as those just described possess dispersing nerve-fibers as well as concentrating fibers and that the act of cutting stimulates these dispersing fibers; in other words that these color cells are doubly innervated. This view was long ago advocated for chromatophores in general by Bert (1875) who failed, however, to advance any very cogent reasons for its acceptance. Aside from what has just been stated, is there any reason for assuming that the melanophores in *Fundulus* are doubly innervated? In answer to this question three kinds of evidence may be considered.

The pharmacological study of the automonic innervation of chromatophores in fishes as carried out by Giersberg (1930) on *Phoxinus* and more especially by Smith (1931a) on *Fundulus* favors the idea of double innervation. Smith in particular used a number of drugs some of which were excitants and others depressants of sympathetic and of parasympathetic nerve-fibers, and concluded, as did Giersberg from his work, that on the whole the results were more favorable to the view of double than of single innervation. A second and more conclusive line of evidence came from Mills' study (1932) of the exact limitations of caudal bands in *Fundulus*. When the edge of a partly blanched band in this fish is scrutinized in detail under conditions in which the rest of the fish is at one time dark and at another pale, individual melanophores are found which respond in an unusual and surprising way. For instance melanophores can be identified which will expand when the fish is on a black background, but which will fail to contract when it is on a white one. Such a condition is difficult to explain except on the assumption that the given melanophore has retained its dispersing nerve-fibers when by the accident of the cut it has been deprived of its concentrating fibers. Clearly single innervation would not suffice to explain this condition. A third line of evidence has been advanced by Abramowitz (1935b, 1936a), who in a study of the regeneration of melanophore nerves in *Fundulus* found somewhat similar conditions at the advancing end of the regenerating nerve. If after the regeneration of the nerve-fibers over a denervated caudal band has got fully under way, the fish is induced to change first pale and then dark. These changes will be registered not only on the fish as a whole, but also on that part of the caudal band in which the nerves have newly formed. Such changes will of course not be seen in the more distal part of the band into which the regenerating fibers have not yet spread. If on a given band the region of transition between the regenerated and the degenerated portions is carefully scrutinized under first the pale phase and then the dark one, the individual melanophores will present highly significant conditions. Some will be found that, like normal melanophores, are capable of full concentration and of full dispersion of pigment; others can be seen that, like fully denervated melanophores, are incapable of either pigment concentration or dispersion; still others will be noticed that can concentrate their pigment, but not disperse it; and finally others will be found that cannot concentrate but can disperse their coloring matter. Of these four classes, as Abramowitz has pointed out, the last two seem inexplicable except on the assumption that each melanophore is provided normally with both dispersing and concentrating fibers and that in the first of these two instances the regenerated concentrating fibers have reached the given melanophore in advance of the dispersing fibers and in the second the reverse is true. Such an explanation, and there appears to be no other, implies that normally these melanophores are doubly innervated.

If then the melanophores in *Fundulus* are doubly innervated, the two sets of nerve-fibers, concentrating and dispersing, must of necessity possess a certain amount of physiological distinctness. It is therefore not surprising that one set, the concentrating fibers, should be easily excited electrically and the other, the dispersing fibers, open especially to activation by cutting. It is probable that both sets of fibers are stimulated by both means, but that one is especially receptive to one type of stimulus and the other to the other. It is not to be supposed that these two kinds of stimuli are in any sense exclusive for the two classes of fibers.

Another agent that has been suspected of playing a part in the color changes in *Fundulus* is the melanophore-activating principle of the pituitary gland, intermedin (Zondek and Krohn, 1932a). The possibilities of the pituitary gland in this respect were tested in *Fundulus* as early as 1924 by Desmond who found that after hypophysectomy, this fish was still able to change under appropriate conditions from pale to dark and the reverse. Desmond, therefore, concluded that the melanophore system of *Fundulus* was not influenced by pituitary secretions. This conclusion was in agreement with observations on blood transfers, for the blood of a dark *Fundulus* when injected into a pale one was found to have no observable effect upon the color of the recipient, nor had that of a pale fish on a dark one (Mills, 1932b; Parker, 1934d). Matthews (1933), without knowledge of Desmond's results, also hypophysectomized *Fundulus* and confirmed Desmond's earlier findings. Matthews, however, observed further that when fresh scales from *Fundulus* were immersed in an extract of the pituitary gland of this fish, the melanophores in the scales contracted. This peculiar response led Kleinholz (1935) to experiment further on this subject with the result that he found that the extract from the pituitary gland of *Fundulus*, though ineffective as a means of color change for normal *Fundulus*, would on injection darken *Ameiurus*, *Rana*, and *Anolis*. This extract would also darken a denervated, pale, caudal band in a pale *Fundulus*. Presumably in a fish in this state the intermedin in its blood is so small in amount as to be unable to compete with the concentrating nerve-fibers by which the fish is kept pale, but when by denervation, as in a pale caudal band, these and all other fibers are excluded from acting on the melanophores, the low concentration of intermedin present in the blood becomes effective enough to darken the pale band, though not sufficient to darken any other part of the fish.

This explanation has in fact been confirmed by Abramowitz (1937a) who, recognizing the great sensitiveness of the frog to intermedin, used this animal as a test for small amounts of this agent. He adopted as a standard frog-unit the amount of intermedin in 0.2 cc. fluid which when injected in the dorsal lymph sac of a hypophysectomized frog would maintain the melanophores of the test animal in expansion for a period of three hours. The pituitary gland in a *Fundulus* of ordinary size, 10 cm. long, was found on ordinary extraction to contain approximately four frog-units though upon special treatment 100 such units could be obtained. Further tests showed that the minimal effective dose of intermedin for the denervated tail melanophores in *Fundulus* was 100 times greater than that for the melanophores of the frog. By tests on the frog Abramowitz showed that the blood from a pale *Fundulus* contained intermedin, but it was in such small amounts as to be ineffective in exciting melanophore expansion in that fish. As the blood of even a dark *Fundulus* on injection into a pale fish does not appreciably darken the second fish (Mills, 1932b; Parker, 1934d), it is improbable that under normal conditions intermedin has any real rôle in the color changes of *Fundulus*. This substance is at best only a mild supplement to the action of the dispersing fibers. Except for the remote possibility of a concentrating pituitary neurohumor indicated by Matthews (1933), the agents concerned with the melanophore changes in *Fundulus* appear to be three in all: concentrating nerve-fibers for blanching, and dispersing nerve-fibers, and, possibly, intermedin for darkening.

Fundulus heteroclitus possesses beside melanophores also xanthophores and guanophores. These two types of color cells have been much less studied than the melanophores. The xanthophores of *Fundulus* have been worked upon by Fries (1927, 1931), Warren (1932), and Abramowitz (1935a, 1936d). They have been shown by Fries to be innervated and to respond independently of the melanophores and by Abramowitz to possess neurohumors different from those of the black cells. Little is known about the guanophores except that they are present in *Fundulus* and respond to adrenalin by dispersion of pigment as shown by Odiorne. These additional pigment cells, the yellow and the white, add to the already complicated picture of the chromatophore system in *Fundulus*.

B. *Ameirus nebulosus*, the common catfish of the fresh-water ponds and streams of the eastern United States, is another fish that is very satisfactory for the study of color changes. Its range in tint is from a pale greenish yellow to an almost full black. The chromatophores in *Ameiurus* appear to be all of one kind melanophores (Parker, 1934e; Odiorne, 1937). In this respect *Ameiurus* is simpler than *Fundulus*. The mechanism of the color changes in *Ameiurus*, as the following account will show, is more complex than that in *Fundulus*. *Ameiurus* is slow in color responses as compared with *Fundulus* and requires hours to accomplish changes that are made by *Fundulus* in minutes. Thus a dark *Ameiurus* will blanch on a white background in from twenty-four to thirty-six hours and will darken in a black one in from fifteen to twenty-four hours (Parker, 1934e). The periods for these changes as given by Abramowitz (1936c) namely for blanching less than two hours and for darkening less than one hour, are shorter than those just noted probably because this worker used somewhat different turning points in his tests. In consequence of the slowness of the color changes in *Ameiurus* as compared with *Fundulus* some experimental procedures easily carried out on the latter are impossible on the former.

Parker (1934e) was unable on applying electrical stimulation to the medulla of *Ameiurus* to elicit blanching as in *Fundulus*, but Abramowitz (1936c) was more successful in that he induced a paling of the tail of *Ameiurus* on stimulating electrically the base of the spinal column. Blanching induced in this way had no effect on dark caudal bands. Thus there is good evidence in *Ameiurus* for the presence of concentrating nerve-fibers. By cutting radial nerves in the tail of a pale catfish well marked dark caudal bands may be produced. These are relatively persistent and may not wholly disappear in a pale fish for a week or more. Their proximal portions blanch earlier than their distal ones. When a second cut is made in the blanched portion of such a caudal band, a secondary band is formed though not as conspicuously as in *Fundulus*. Nevertheless in *Ameiurus* such secondary bands are easily demonstrable and fully support the assumption that dispersing nerve-fibers are present in this fish as in *Fundulus*. This conclusion was confirmed by Abramowitz (1935b) in his study of the regeneration of chromatophore nerves in *Ameiurus*.

The pituitary gland in *Ameiurus* is a very efficient organ for color change as contrasted with the corresponding structure in *Fundulus*. When the pituitary gland is removed from an *Ameiurus*, the fish will still change pale or dark under the influence of its two sets of autonomic nerves, but a pale caudal band in such a fish will persist for some time after the fish has become dark, a condition which does not prevail in a fish normal in respect to its pituitary gland. Here the intermedin from the gland darkens the pale band as it does the rest of the fish whereas in the absence of the gland no such darkening occurs. As might be expected the blood from a dark normal *Ameiurus* will induce a dark spot when injected into a pale individual, whereas that from a hypophysectomized *Ameiurus*, even though the animal is dark, has no effect upon the color of the recipient. The dispersing nerve-fibers, unlike the pituitary gland, produce no blood-soluble agent.

In addition to intermedin *Ameiurus* has been suspected of possessing a concentrating neurohumor whose properties resemble those of adrenalin. Abramowitz (1936c) noticed that from two to five minutes after a catfish had been much disturbed by movements directed toward its capture, it would often blanch generally. This change did not apply immediately to dark caudal bands that it might possess. Such bands, however, would remain dark for only some five to ten minutes after the rest of the fish had blanched when they would then also blanch. The fish would then gradually darken followed after an interval of time by the bands. This whole reaction has a striking resemblance to the excitement pallor which has been described in lizards by Redfield (1918) and by Hogben and Mirvish (1928a, 1928b) and which was attributed by Redfield to adrenalin. It is natural that Abramowitz should conclude that the agency responsible for such pallor may be adrenalin or a substance like it in effect. How much such an agent may have to do with the habitual color changes in *Ameiurus* is still to be ascertained.

The melanopore system of *Ameiurus* looked on as a whole is activated by a greater number of agents than is that in *Fundulus*. In addition to concentrating and dispersing nerve-fibers *Ameiurus* possesses a well-developed pituitary control and probably some form of concentrating neurohumor whose action resembles that of adrenalin. Of these several agents it was early believed that the dispersing nerves were probably the most efficient (Parker, 1934e), but it has since been shown with reason that intermedin is in all likelihood the most effective factor (Abramowitz, 1936c; Veil, 1937; Osborn, 1938).

From the standpoint of the present discussion *Fundulus* and *Ameiurus* appear to have been more fully studied than any other teleosts. Veil (1935), however, has advanced much evidence that in *Cyprinus* and *Carassius* in addition to nerves, the pituitary secretions play an important part in color changes. A few observations looking toward the neurohumoral interpretation of color changes have been recorded for the squirrel fish, *Holocentrus ascensionis*, an inhabitant of the subtropical waters of Bermuda. This fish changes from red to white and back again with great rapidity (Smith and Smith, 1935). The averages from a number of time records for these changes at 19° C. are red to white about nineteen seconds and white to red a little over six seconds. These vary rapid changes depend upon the contraction and expansion of erythrophores which give evidence of being doubly innervated. Apparently no other agents have a part in these color changes, for, though the fishes blanch to injected adrenalin and redden to pituitrin, they are not influenced by blood transfers nor by injections of extracts from their own pituitary glands (Parker, 1937c). In these respects *Holocentrus* seems to be much like *Fundulus* was believed to be when its color changes were first described. One important fact that these rather scanty records from *Holocentrus* disclose is that though this fish is unusually rapid in its color changes, it nevertheless employs apparently much the same chromatophore mechanism as the more slowly responding species do. It is very desirable that fuller and more extended studies be carried out on this and other rapidly responding teleosts.

The chromatophore systems in the few teleosts which have thus far been studied from the neurohumoral standpoint appear to be far from uniform. Intermedin was not identified in *Holocentrus*, is present in *Fundulus* only in insignificant amounts, but is an active agent in *Cyprinus* and *Carassius* and especially in *Ameiurus*. Adrenalin or an adrenalin-like neurohumor may occur in *Ameiurus*. Nerves play a direct part in *Cyprinus* and *Carassius* and in *Fundulus*, *Ameiurus*, and *Holocentrus* these are known to be of two kinds, concentrating and dispersing.

5. *Lipohumors*

It was stated in the concluding paragraph of the last section that nerves play a direct part in the blanching and darkening of certain teleosts, particularly of *Fundulus* and of *Ameiurus*, and in the blanching of the elasmobranch *Mustelus*. Is such direct nerve action radically different from the humoral control of color cells, as has been assumed by Hogben, or are both types of control, nervous and humoral, examples of one kind of activation? This question can be approached best by a further inquiry into the nature of the integumentary bands and patches produced by denervation. Such bands and patches were observed and studied in the chameleon as long ago as 1852 by Brücke, but it remained for Pouchet (1876) to point out that in fishes at least darkened patches thus produced were not permanent, but became in course of time as pale as the rest of the animal. Von Frisch (1911a) also noted that the contrast between the denervated dark area and the pale general surface in the minnow may vanish by the blanching of the dark area in from twelve to fourteen days. This observation was confirmed by Smith (1931b) except in so far as the time was concerned. According to Smith the blanching of a dark area in the minnow may be accomplished in the course of several days instead of weeks. Smith further noticed that the band or spot on the minnow became pale only if the fish was kept on a white, illuminated background. On a black one the area remained dark as the rest of the fish did. The blanching of dark areas was also observed by Zoond and Eyre (1934) in the chameleon though in this animal the change required six to eight weeks. It may well be that these several instances, all examples of blanching, may depend in different cases upon different factors and thus call for separate explanations, but, however this may be, the fact is clearly recognized by all who have worked upon *Fundulus* that the dark caudal bands produced by incisions made in the tail of this fish blanch in the course of about two days if the creature is kept on an illuminated white background. In its time relations this instance is like that of the minnow as described by Smith and not like the chameleon. *Fundulus* moreover resembles the minnow in that its caudal bands fail to blanch when the fish is kept continuously dark in tint.

It was first shown by Mills (1932b) that when a caudal band in *Fundulus* begins to fade, it does so not uniformly throughout its whole breadth, but first on its periphery. Thus the edges of the band are lost earlier than the axis, that is, the melanophores on the edges concentrate their pigment before those in the axis do. This was subsequently demonstrated by Parker (1935c) who with the aid of Abramowitz photographed from hour to hour the same area in a fading caudal band of *Fundulus*. It can be seen by comparing Figure 4 which was taken from a caudal band a quarter of an hour after it had been formed with Figure 5 from the same place in the same band six and a quarter hours after the initiating cut had been made. The concentration of pigment in the peripheral melanophores in Figure 4 is noticeable as compared with what is to be seen in these cells in Figure 5.

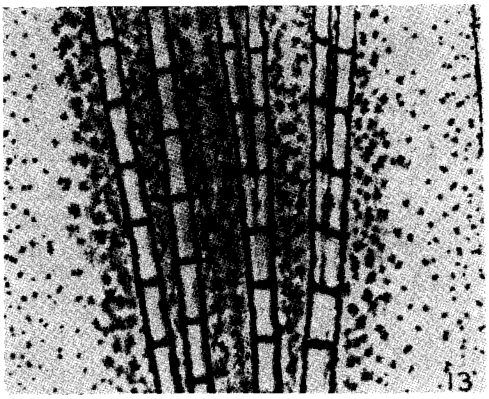

FIGURE 4. A microphotograph of a part of a caudal band in a living *Fundulus* 15 minutes after the cut had been made by which the band was initiated. The band is formed in the region of four fin-rays which are branches from a single ray at the base of the tail (below in the figure). The melanophores composing the band are fully expanded as contrasted with those of the rest of the tail which are, in most instances, fully contracted (right and left of the band in the figure). Parker, 1935 c, pl. 3, fig. 13.

If a small amount of adrenalin is injected into a *Fundulus* with a well marked caudal band, the band will blanch uniformly over its whole width. This is what would be expected from an agent carried in the blood and lymph and thus brought to act on the band over its whole inner surface. The natural blanching of a caudal band does not take place in this way, but, as just indicated, proceeds from the edges of the band toward its axis. It must therefore depend upon some agent that comes from the adjoining pale field, an agent probably the same that has induced the general paleness of that field and that has worked slowly from the periphery into the band.

If this view of the normal blanching of a caudal band is correct, such bands should require different lengths of time to become pale depending upon their width and this seems to be true. Thus a band one millimeter wide in the tail of *Fundulus* will blanch fully in about one day, whereas one two millimeters wide will require for the same change some two days (Parker, 1934a). Abramowitz (1936c) has made similar measurements on *Ameiurus* and has recorded that a band of the width of a single ray will blanch in two days, one of two rays in five days, and finally one of three rays in ten days. All these observations support the conclusion that the blanching of a dark caudal band in a pale fish is due to the invasion of the band laterally by an agent from the adjacent pale field. This agent is unlike adrenalin in that it gives no evidence of being soluble in blood or other watery fluids. It spreads, however, through the tissues and presumably takes its course by way of their lipoid components. It is believed to

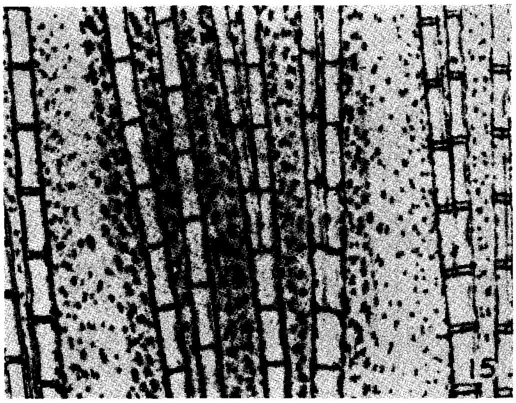

FIGURE 5. A microphotograph of the same part of the caudal band in a living *Fundulus* as that shown in Figure 4 but taken six and a quarter hours after the initiating cut had been made. The greater concentration of the pigment in the peripheral melanophores of the band as compared with that in the axial melanophores can be clearly seen. Parker, 1935 c, pl. 3, fig. 15.

be oil-soluble and to originate from the terminals of the concentrating, autonomic nerve-fibers and to affect not only the melanophores with which these fibers are immediately associated, but to spread to and affect the denervated melanophores of the caudal band itself. The rate at which such bands blanch would then be a measure of this spread, roughly half a millimeter a day in *Fundulus*.

After a caudal band in a pale *Fundulus* has blanched, the fish may be darkened by being placed on a black background with the result that a pale band will be left in the tail of a dark fish. In course of time such a band will darken if the fish is kept dark just as a dark band will blanch on a fish kept pale. All such changes in bands are accomplished with a certain amount of lag as compared with the change in the tint of the fish as a whole. Such a lag is quite consistent with the idea of the invasion of the band by a neurohumor from the adjoining fields whereby the change in the band is believed to be produced (Parker, 1933a, 1933b, 1934a, 1935d).

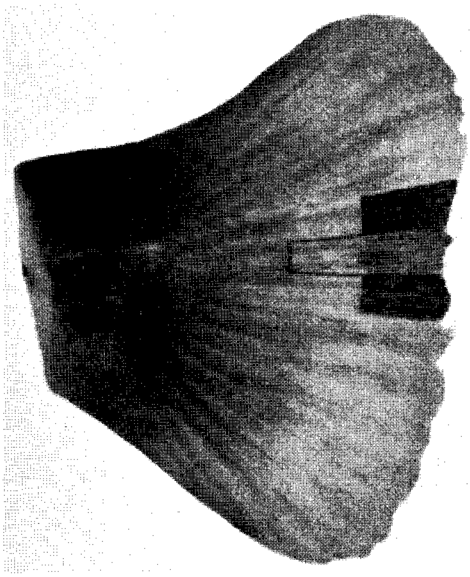

FIGURE 6. Diagram of a caudal fin of a hypophysectomized catfish, *Ameiurus*, with a faded caudal band between two newly cut dark half-bands. The half of the faded band not flanked by the new dark bands has remained pale; the half flanked by the dark bands has darkened slightly. Parker, 1934 e, pl. 1, fig. 5.

Almost everything that has been mentioned concerning the caudal bands in *Fundulus* may be duplicated for the caudal bands of *Ameiurus* (Parker, 1934e; Abramowitz, 1936c). In this fish in addition an interesting experimental test of the influence of dark lateral fields on a pale band can be made in the following way. If an *Ameiurus* with a dark caudal band is placed on a white, illuminated background, the dark band will blanch in a few days. If now two new dark bands are made by cutting the fin rays adjacent to that of the blanched band, and the cuts of the new bands are made not near the root of the tail as that for the blanched band was, but about half way out on the rays toward the tip of the tail, the result will be a central pale band whose distal half will be abutted laterally by dark bands. The proximal half of the pale band will be surrounded only by the pale portion of the tail. Under such circumstances the distal half of the pale central band which is flanked by the dark half-bands will be seen to darken slowly, whereas the proximal half will remain pale (Fig. 6). This experiment shows quite clearly how adjacent dark areas may bring about a dispersion of pigment in a pale area, a change easily understood from the standpoint of an invading dispersing neurohumor.[1]

All these observations on *Fundulus* and on *Ameiurus* when taken together support the conclusion that the changes in tint of caudal bands in these fishes are due to the invasion of the bands, be they pale or dark, by agents from the opposing adjacent fields and that these agents are dispersing or concentrating neurohumors produced by the appropriate sets of nerve-fibers in these fields. Such neurohumors, insoluble in water, are believed to spread from their regions of origin through the lipoid constituents of the tissues to the melanophores in the denervated bands. In these respects *Fundulus* and *Ameiurus* seem to be essentially alike.

The dogfish, *Mustelus canis*, has a type of melanophore innervation quite unlike that of *Fundulus* and *Ameiurus*. In *Mustelus* the normal darkening of the fish is not dependent upon the direct action of nerves, but upon intermedin. Its blanching, however, involves concentrating nerve-fibers, a state of affairs which, as already noted, appears to be peculiar to *Mustelus* as compared with the other elasmobranchs thus far investigated. When integumentary nerves in

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[1] Since the preparation of the present paper Matsushita (1938) has published a study of the color changes in the Japanese catfish *Parasilurus* in which he has repeated this experiment and devised several others to the same end all of which confirm the idea of lateral neurohumoral transmission.

Mustelus are cut, as for instance in the pectoral fin, a pale band is formed instead of a dark one. This pale band may be excited electrically (Parker, 1935a) as well as by cutting. After it has faded it may be revived by recutting (Parker, 1936b). When intermedin is absent from the blood or low in amount, the edges of such a band are sharp and straight; when this agent is present in functional quantities in the blood, the band commonly has irregular outlines or may be in large part obliterated (Parker, 1937d). As the pale band is strictly limited to the denervated area and never spreads noticeably into the dark surrounding fields, but may be encroached upon by the dispersing effects of intermedin, it is concluded that it may result, as with the pale band in *Fundulus* and *Ameiurus,* from a lipoid-soluble neurohumor produced by the terminals of the concentrating nerve-fibers.

If the concentration of melanophore pigment in *Mustelus* and its dispersion as well as its concentration in *Fundulus* and in *Ameiurus* are dependent upon neurohumors insoluble in aqueous media but soluble in oily materials, it ought to be possible to extract such neurohumors by the appropriate treatment of fish skins. This has been attempted and with reasonable success in *Mustelus* and in *Ameiurus.*

The phase of *Mustelus* that is suspected of being associated with an oil-soluble neurohumor is the pale one and the parts that show this phase best are the fins. Smooth dogfishes were therefore put in a white-walled illuminated tank and after a few days, when they had become fully blanched, they were killed and their fins removed. It was a matter of good fortune that in the preparation of the fins the cutting of nerves intensified the paleness rather than the reverse. The fins immediately after their removal were ground to a pulp and the pulp from the fins of one ordinary dogfish was then thoroughly mixed with about two cubic centimeters of Italian olive oil. This mixture was further ground by hand for about half an hour in a rough porcelain mortar till it reached the consistency of a thick paste and then it was set aside to undergo extraction. In most instances it was sterilized by heat before it was extracted. Its extraction was carried on at the low temperature of an ordinary ice box. After the paste had stood some fifteen hours, it was mixed with its own volume of sterile seawater and the thick liquid that resulted was set aside to allow the oil to rise to the top. In this way there was collected a crude water-and-oil emulsion which after having been roughly filtered through sterile cheesecloth, was vigorously agitated and injected subcutaneously in appropriate amount into a dark dogfish. Very soon after the injection had been made there commonly appeared on the skin of the dogfish and a little in front of the point of insertion a few small pale spots which, however, soon disappeared. As these spots were to be seen when small amounts of indifferent fluids were injected as controls, they were regarded as of purely operative significance. In from one to two days after the injection relatively large pale areas made their appearance in the skin immediately over the region into which the fin extract had been introduced (Fig. 7). These large areas were very persistent and, as could be shown under a low power of the microscope, they were produced by the concentration of melanophore pigment. That the pale skin included in these spots was essentially normal was demonstrated by the injection of pituitrin into a fish with such a spot. Shortly after an injection of this reagent had been made, particularly if the region of injection was close to the pale spot, it disappeared by the darkening of its melano-

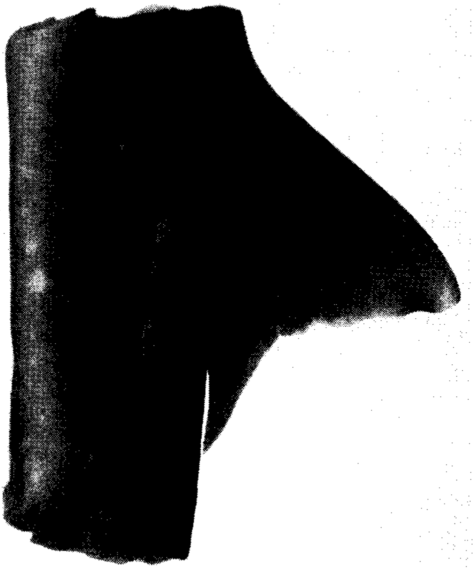

FIGURE 7. Left side of the trunk of a smooth dogfish, *Mustelus*, in the region of the anterior dorsal fin showing a pale spot due to an injection of 0.5 cc. of an emulsion of olive-oil extract from blanched fins in seawater made a little over a day previously. Parker, 1935 b, p. 840, fig. 1A.

phores only to return after a few hours as the effect of the pituitrin wore off.

These large pale spots were not produced by injections of seawater, oil, oil extracts of dark fins or of muscle, seawater extracts of pale fins, or defibrinated blood from pale or dark fishes (Fig. 8). They were produced from oil extracts, sterilized or not sterilized, of pale fins and from cold ether extracts and Soxhlet ether extracts from the same. These various tests led to the conclusion that the induced pale areas in *Mustelus* are due to the action of some substance that can be extracted from the pale fins of this fish by olive oil or ether. The few known properties of this substance aside from its solubility in olive oil and ether and its insolubility in water are its resistance to dry heat up to 110° C., to treatment with two per cent sodium hydroxide and with two per cent hydrochloric acid (Parker, 1937a). This substance may be extracted from fins that have been kept in a dry state in the laboratory for a year (Parker, 1938b). It must therefore be a relatively stable material, such for instance as one of the sterols.

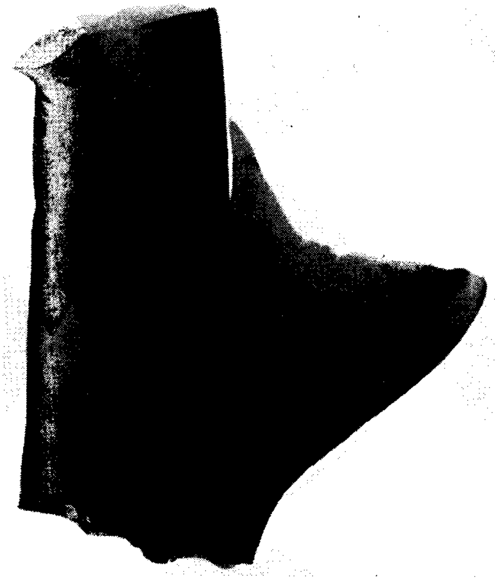

FIGURE 8. Right side of the same dogfish as is illustrated in Figure 7, showing no change of color after the injection of 0.5 cc. of an emulsion of pure olive-oil in seawater. Parker, 1935 b, p. 840, fig. 1B.

The only other fish that has been examined for the possible presence of oil-soluble neurohumors is the catfish *Ameiurus*. In this fish the dark phase is the one favorable for study. Extracts of the fins and skins of dark catfishes were prepared as in the case of pale dogfishes, and the final extract was injected subcutaneously into pale catfishes. This operation was followed in a little less than an hour by the formation of dark splotches on these fishes (Fig. 9). Such splotches, which were caused by the dispersion of pigment in the melanophores of the region concerned, disappeared spontaneously after a few days. When they were first formed, they could be temporarily obliterated by an injection of adrenalin. Extraction of the skin of *Ameiurus* by ether, hot or cold, yielded residues that were slightly active in darkening the skin, but they were by no means so effective as were the ether extracts from *Mustelus*. However, the evidence from the catfish supports the view that in *Ameiurus* a dispersing neurohumor is present which in its solubility in oil and in its insolubility in water resembles the concentrating neurohumor from *Mustelus*.

From what has been stated in the preceding discussion, it is evident that in addition to those neurohumors, such as intermedin and adrenalin, that are soluble in water, there are others insoluble in aqueous media, but soluble in oil, ether and

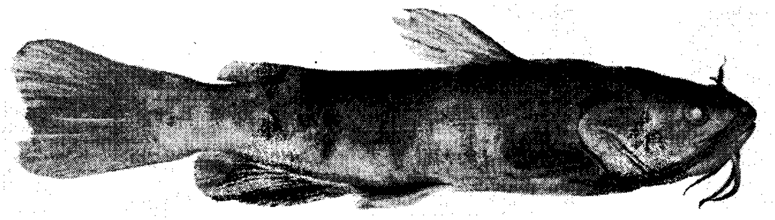

FIGURE 9. A catfish, *Ameiurus*, into which an injection of olive-oil extract of the dark fins and skins of five other catfishes had been made anteriorly from the black dot below the adipose fin. The resulting dark areas are superficial to the region where the injected fluid escaped from the needle point. Parker, 1935 e, pl. 1, fig. 2.

the like. These two classed may be designated conveniently as hydrohumors when they are soluble in water and lipohumors when they are soluble in lipoids, fats, or fat solvents. Lipohumors are from their nature essentially stationary in the animal body and can at best diffuse only slowly from place to place as compared with hydrohumors which may be carried rapidly in the blood and lymph from one part of the body to another. Lipohumors therefore have not attracted the attention that hydrohumors have though the significance of the lipohumor in animal economy may be far from small. The parts played by the lipohumors in the nervous excitation of melanophores show that the distinction often drawn between the nervous and the humoral activation of these color cells is unimportant. In both types of excitation neurohumors are involved. The chief difference is that in hydrohumors the substance comes usually from a remote source, in lipohumors from one close to the color cell.

IV. NEUROHUMORS

It must be evident from what has been stated in the preceding section that the activation of vertebrate chromatophores is dependent upon several neurohumors. First among these is intermedin which appears to play a part in the color changes of all chromatic vertebrates whose pituitary secretions have thus far been examined. This range includes representatives from the cyclostomes to the lizards. Even in *Fundulus* where the influence of intermedin seems to be at its lowest ebb, its effects on the melanophores are slight rather because of the resistance of these color cells than in consequence of any insufficiency in the secretion. Intermedin like many other internal secretions probably has other functions than that of controlling pigment cells, a belief supported by the fact that it is an abundant product in birds and mammals where active chromatophores do not occur. Intermedin is the material which Hogben and his associates have designated in their discussion of vertebrate color changes as the B-substance. Throughout the vertebrates it is the usual means of dispersing melanophore pigment.

A second significant vertebrate neurohumor for color changes is adrenalin. This is by no means so commonly present nor so uniform in action as intermedin. On injection it induces almost invariably a concentration of melanophore pigment whereby the animal blanches. Kleinholz (1936) has pointed out, however, that in *Anolis* adrenalin not only causes a generalized pallor but also induces in this lizard certain dark patches and mottlings. It was shown by Bigney (1919) that when adrenalin is injected into a frog, the integumentary melanophores concentrate their pigment, but the retinal ones disperse theirs. Thus in the melanophores of the same animal adrenalin induces opposite effects. Apparently adrenalin plays a part in the normal color changes of certain lizards such as *Phrynosoma* (Redfield, 1918; Parker, 1938a), and *Anolis* (Kleinholz, 1936b), and in the catfish *Ameiurus* (Abramowitz, 1936c) in all of which it is associated with what Hogben and Mirvish (1928a, 1928b) called excitement pallor. To what extent it may be identified in other chromatic vertebrates remains to be discovered. Its usual source is the medulla of the adrenal glands or other similar but less specialized vertebrate tissues. Closely related to it, if not identical with it, is the neurohumor sympathin (Cannon and Rosenblueth, 1935) as produced by the sympathetic terminals in mammals. Too little is known of the W-substance of Hogben to relate it to adrenalin. Its physiological effect on melanophores is much the same as that of adrenalin, but its assumed origin from the pars tuberalis of the pituitary complex (Hogben and Slome, 1931, 1936; Hogben, 1936) is not especially suggestive of a relation to adrenalin. It may resemble adrenalin only in so far as the similarity of its melanophore response is concerned. Although adrenalin may stimulate the nervous mechanism of the chromatophore system, it certainly also acts directly on the melanophores themselves for, after these color cells have been denervated, they continue to respond to this neurohumor (Parker, 1934b).

In addition to the two neurohumors, intermedin and adrenalin, certain fishes at least appear to possess oil-soluble neurohumors, lipohumors, which are believed to emanate from the controlling autonomic nerve-terminals. One of these, as already noted, is concerned with the blanching of the dogfish *Mustelus canis* and may be provisionally designated as lipohumor A (Parker, 1935b). What appears to be another is effective in darkening the catfish *Ameiurus nebulosus* (Parker, 1935e) and might be set down as lipohumor B were it not for the fact that the crude product containing lipohumor A from the dogfish when injected into *Ameiurus* darkens instead of blanches this fish. Thus the blanching agent of *Mustelus* acts in the reverse way on the melanophores of *Ameiurus* (Parker, 1938b). If this blanching lipohumor from *Mustelus* is the same as the darkening one from *Ameiurus*, then there must still be another lipohumor in *Ameiurus* to account for its blanching. That one neurohumor such as A can concentrate the melanophore pigment in *Mustelus* and disperse it in *Ameiurus* is not without precedent, for, as Carlson (1935) was first to point out, the crustacean eye stalk neurohumor concentrates the pigment in the dark chromatophores of such shrimps as *Palaemonetes*, but disperses it in the crab *Uca*. These rather remarkable reversed reactions can be accepted, however, only provisionally, for they are all based upon reactions to crude extracts. After these extracts have been studied further, it is entirely possible that what has been assumed to be a single agent may prove to be more than one and thus give ground for other assumptions than those advanced at present.

This brief account of the vertebrate neurohumors, intermedin, adrenalin, and the one or more lipohumors is based almost exclusively on the reactions of melanophores. But a number of vertebrates possess other chromatophores than black ones such, for instance, as xanthophores, erythrophores, guanophores, and the like. Are these additional color cells controlled by the same neurohumors as the melanophores are or do they possess activating hormones peculiar to themselves? This question cannot be answered with any fullness because of lack of information. The responses of xanthophores in *Fundulus*, however, as worked out by Fries (1931) and by Abramowitz (1936d), show that the activators of these cells must be distinct from those of the melanophores. Thus on a black background both xanthophores and melanophores are expanded, on a white one both are contracted, on a blue one xanthophores are contracted and melanophores are expanded, and on a yellow one xanthophores are expanded and melanophores contracted. Thus expanded xanthophores may accompany expanded or contracted melanophores and the same is true of contracted yellow cells. That the xanthophores react independently of the melanophores appears to be probable. If they are thus independent, it would be necessary to assume separate sets of neurohumors, one for the melanophores and another for the xanthophores. Whether or not other types of chromatophores such as the erythrophores and guanophores possess their own systems of neurohumors is still to be ascertained, but the analysis of this problem has already gone far enough to show that the list of the vertebrate chromatophoral neurohumors is one of increasing numbers rather than the reverse.

The number of chromatophoral neurohumors in crustaceans has already been discussed at some length. Judged from the normal color responses of certain shrimps as worked out by Brown (1935) there appears to be ground for the assumption of several neurohumors, a view which Abramowitz has designated as the multiple theory of chromatophoral activators. Judged from the simplicity of the sinus gland from which the one or more of these neurohumors appear to proceed and from the highly differentiated condition of the chromatophores in different crustaceans the diversity of responses has been placed by Abramowitz (1937b) with the effectors rather than with the exciting agent. In fact Abramowitz assumes the possibility of a single neurohumor to account for the chromatophoral changes in crustaceans. This view, the unitary theory, is not supported by what is known for the chromatophoral system of the vertebrates nor has it been worked out in detail by Abramowitz for the crustaceans. Its possibilities must, however, be admitted, though the probability of its correctness seems distinctly remote.

An interesting unifying factor in the whole system of chromatophoral neurohumors is seen in the relation of these agents from one species of animal to the chromatophores of another species particularly where the species tested are from different phyla as, for instance, arthropods and vertebrates. It was shown early by Hogben and Winton (1922a) that intermedin from the ox was as fully effective in the melanophore responses of the frog as its own intermedin was. Koller (1928) also demonstrated that extracts from the eyestalks of several species of *Leander* and from *Crangon* would stimulate the chromatophores in species other than that from which the extract had been made. These observations were extended and confirmed by Koller and Meyer (1930), Kropp and Perkins (1933), Carlson (1935), Kleinholz (1937) and Hanström (1935, 1937). Koller and Meyer (1930) also showed that not only would the extract from one species of crustacean induce color changes in another, but that extracts from the eyestalks of *Crangon* and of *Praunus* would contract the melanophores of the fishes *Gobius* and *Pleuronectes*. These interphylar reactions were extended by the work of Meyer (1930, 1931) and of Kropp and Perkins (1933b) and Perkins and Kropp (1932), who made the interesting discovery that the crustacean eyestalk extract, which blanched the shrimps from which it was taken, darkened the skin of frog tadpoles. This darkening of the skin by crustacean eyestalk extract was observed in the elasmobranch *Mustelus,* the teleost *Ameiurus,* the common American frog, and the Carolina lizard *Anolis* by Abramowitz (1936e) who also noted an expansion of the erythrophores in the teleost *Chrosomus* by the same agent. Abramowitz further pointed out that intermedin when injected into a pale fiddler crab (*Uca*) induced a dispersion of its black pigment as its own eyestalk extract did. This observation confirmed the earlier one of Böttger (1937) who showed that intermedin could darken *Crangon.* Thus it was demonstrated that not only crustacean neurohumors could activate vertebrate melanophores, but that vertebrate intermedin could excite crustacean chromatophores. Because of the similarity of chromatophore responses to intermedin and to the eyestalk extract Abramowitz (1936b, 1937b) was led to speculate on the possible identity of intermedin and the eyestalk neurohumor.

Having described briefly the neurohumors that are known to be associated with chromatophores, it may not be inappropriate to offer a general definition for this class of substances. A neurohumor may be said to be a hormone produced by nervous tissue or by glands appended to that tissue and serving as an activator or an inhibitor of other nervous tissue or its effectors. Neurohumors as thus defined include not only the substances discussed in this communication, but other agents such as acetylcholin about whose exact relation to chromatophores there appears to be some uncertainty (Wunder, 1931; Parker, 1931, 1934c; Smith and Smith, 1934; Bogdanovich, 1937; Beauvallet, 1938; Chin, 1939).

It does not include such hormones as the original one, secretin, nor those included under the general heads of androgens and oestrogens. The inclusion of intermedin under neurohumors may arouse some comment because of the embryonic source of the part of the pituitary gland concerned with the production of this substance, but such comment seems unnecessary, for the definition of a neurohumor as just given is avowedly a physiological one and not a morphological one. Abramowitz has implied (1936c, 1937c) that the term neurohumor is limited to those hormones that emanate from nerve terminals as do the lipohumors herein described, but this implication was due apparently to a misunderstanding for which a lack of clearness in the writer's papers was probably responsible.

The term neurohumor (Fredericq, 1927) is synonymous with the somewhat less concise one of neurohormone (Huxley, 1935). It is also an equivalent of the common designation chemical activator. This last term implies that such agents act chemically on the receptive cells. That their action is not necessarily chemical, but may be physical in character has already been intimated by Abramowitz and Abramowitz (1938). From this standpoint the term chemical activator seems to imply too much. Nor is there any part of it that relates it to nervous activity especially. In derivation chemical activator is rather the equivalent of the simple term hormone. For these reasons this term seems less desirable than the other two of which neurohumor is slightly the more concise.

It has been found convenient to divide neurohumors into two classes (Parker, 1935b) hydrohumors or those soluble in water and consequently such as may be carried in the circulating fluids of animals, blood, lymph, and the like, and lipohumors of those soluble in fatty and oily materials and that spread probably exclusively by diffusion from cell to cell. In consequence of their solubility in water hydrohumors are commonly capable of exerting almost at once an influence over the whole of a given animal. Lipohumors on the other hand spread very slowly and are chiefly local in their action.

These various substances are the kind of agent presupposed by the neurohumoral hypothesis (Parker, 1932), a conception according to which all the interrelations between receptor cells and neurones, between one set of neurones and another, and between neurones and their appended effectors are by means of specific substances, the neurohumors, rather than by purely electrical steps. So far as the relations of crustacean and vertebrate chromatophore nerves to their end-organs are concerned, there seems to be abundant substantiation of this hypothesis.

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AMPHIBIANS AND REPTILES IN NEVADA[1]

By Jean M. Linsdale

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Although many naturalists study both amphibians and reptiles, there is little reason to include these two groups of vertebrates in a faunal report on such a desert region as Nevada, other than the similarity in method of preserving specimens. The great contrast in the life histories of these two kinds of animals is emphasized in their dissimilar responses to environmental conditions in the Great Basin. While one characteristically inhabits only the wettest situations, the other occupies and is especially adapted for life in the driest situations.

The University of California Museum of Vertebrate Zoology has carried on zoological exploration in Nevada, under the stimulation of its founder, Miss Annie M. Alexander, since the early years of its existence. Since 1927, renewed effort in that area has brought large collections representing all the groups of terrestrial vertebrates. On each expedition the collectors have been on the lookout for specimens of amphibians and reptiles in addition to their main objectives which usually were concerned with mammals or birds. Altogether more than 4,000 specimens of these cold-blooded vertebrates have been assembled and they form the basis for this report.

Names of persons who have had a part in assembling this material, a list of most of the localities where specimens were obtained, as well as other information of faunal import for this area may be found in my recent report on The Birds of Nevada (Pac. Coast Avifauna no. 23, 1936, pp. 1–145). Fifty accessions contain 4,213 specimens.

As was suggested in the preceding paragraph, the present faunal report is the result of field work by many persons. I am grateful to all of these collectors and especially to E. Raymond Hall, Ward C. Russell, Henry S. Fitch, and Tom Rodgers who made special efforts to get needed specimens. In actual preparation of the report much help was received from Mr. Rodgers who made the maps and who, with Mr. Walter Paxton, catalogued and measured many specimens. I am thankful to the persons in charge of collections from which records were obtained (see p. 198). Mr. Lawrence M. Klauber and Mr. Charles M. Bogert have been generous in giving me results of their field work in Nevada. Dr. Joseph Grinnell has contributed to this report by advice and in other ways. Assistance in preparation of this publication was rendered by personnel of Works Progress Administration O.P. No. 465-03-3-193.

Accounts of Species

The sequence of genera in this report is that of the Check List of North American Amphibians and Reptiles (3rd ed.) by Stejneger and Barbour (1933). As in that check list the species and subspecies are here arranged alphabetically. Departures from that authority are chiefly in matters of taxonomy where recently accumulated material seems to require different treatment.

Items in each account are arranged according to a plan which is intended to include essential information but at the same time to allow sufficient flexibility to discard less significant matter. For each kind the adopted scientific name with authority is given as a heading. Next below this is a vernacular name selected usually for specific application; sometimes no finer distinction than the genus is feasible. Citation is given to the original description and the type locality is indicated for each form. When a kind has been attributed to Nevada by some other name than the one adopted here, at least one reference is given to each such synonym, but no effort has been made to compile a complete synonymy.

Because the ranges as defined in most reference works are not completely satisfactory or easily available, a brief statement of general range is given for each form. Following this is a summary of the nature of the occurrence of each form in Nevada. Then locality records are given insofar as I have been able to verify them. These are arranged by counties listed in general north to south order in the following sequence: Washoe, Storey, Ormsby, Douglas, Lyon, Humboldt, Elko, Pershing, Churchill, Lander, Eureka, White Pine, Mineral, Esmeralda, Nye, Lincoln, Clark. For most of the localities locations of specimens are given where known; for some, published references are given, and a few are accepted from manuscripts. Following the list of locality records comes material of systematic significance and a summary of the natural history of each form as known from Nevada. Most of my own observations on the natural history of these animals have been published already in the American Midland Naturalist (1938, vol. 19: 20–32), and they are not repeated here.

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[1] Contribution from the Museum of Vertebrate Zoology of the University of California.

Abbreviations

In the paragraphs giving locality records, locations of the specimens are given where known and the following abbreviations are used to designate collections which contain them:

Acad. Nat. Sci. Phila.	Academy of Natural Sciences of Philadelphia
Calif. Acad. Sci.	California Academy of Sciences
Klauber coll.	Collection of L. M. Klauber, San Diego, California
Mus. Vert. Zool.	Museum of Vertebrate Zoology, University of California
San Diego Soc. Nat. Hist.	San Diego Society of Natural History
Stan. Univ.	Stanford University
U. C. L. A.	University of California at Los Angeles
U. S. N. M.	United States National Museum
Univ. Kans.	University of Kansas
Univ. Mich.	Museum of Zoology, University of Michigan

AMPHIBIA

Order **Salientia**

Suborder Linguata

SCAPHIOPODIDAE

Scaphiopus hammondii Baird

Western Spadefoot Toad

Original description.—*Scaphiopus hammondii* Baird, Pac. R. R. Rept., **10**, 1859, Abbot's report, pt. 4, no. 4, p. 12, pl. 28 (figs. *2a*, *2b*, *2c*, *2d*) (Fort Reading [near Redding, in Shasta County], California).

Synonyms for Nevada.—*Scaphiopus intermontanus* Cope, 1883, pp. 15, 18.

Spea hammondii intermontana Cope, 1889, p. 304.

Range.—The species occurs in western North America from British Columbia south to Mexico and east to the western edge of the Mississippi Valley. Several geographic races have been distinguished but the whole group has not yet been satisfactorily studied.

Occurrence in Nevada.—Has been found at widely scattered localities throughout the state south to the vicinity of Bunkerville in the Virgin River Valley near the eastern border of the state and just south of the northern boundary of Clark County. Localities of capture are mainly at levels between 4,000 and 6,000 feet; extremes are about 1,700 feet at the southernmost locality and 7,500 feet in Greenmonster Cañon, Monitor Range. Most of the localities are on the floors of the larger valleys. Dates of capture of adults are mostly in the early summer months from the latter part of May through July. Extremes are in Clark County, March 28, 1923, and October 2, 1931. Farther north an early date is April 24, 1930, 5,500 feet, in Smoky Valley. Late records are on September 5 and 8, 1930, at 6,800 and 6,500 feet, in northern White Pine County.

Nevada localities (Fig. 1) (380 specimens in Museum of Vertebrate Zoology).—

Washoe County: 4½ miles southwest of Diessner, 5,800 feet (Mus. Vert. Zool.); The Willows, Pyramid Lake (U. S. N. M.); Pyramid Lake (Calif. Acad. Sci.; U. S. N. M.).

Ormsby County: Carson City (U. S. N. M.).

Humboldt County: Thousand Creek Hot Springs (Mus. Vert. Zool.); Virgin Valley (Mus. Vert. Zool.); Big Creek at base of Pine Forest Mountains (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); 1 mile north to 10 miles southwest of Winnemucca (Mus. Vert. Zool.).

Elko County: Marys River, 22 miles north of Deeth (Mus. Vert. Zool.); Piñon Range (Univ. Mich. Mus.); Lower Annie Creek (Univ. Mich. Mus.); Humboldt River Valley (Univ. Mich. Mus.); James Cañon (Univ. Mich. Mus.); Carlin (Univ. Mich. Mus.); Maggie Cañon (Univ. Mich. Mus.); Lower Maggie Creek; (Univ. Mich. Mus.); 10 miles southwest of Midas (Mus. Vert. Zool.).

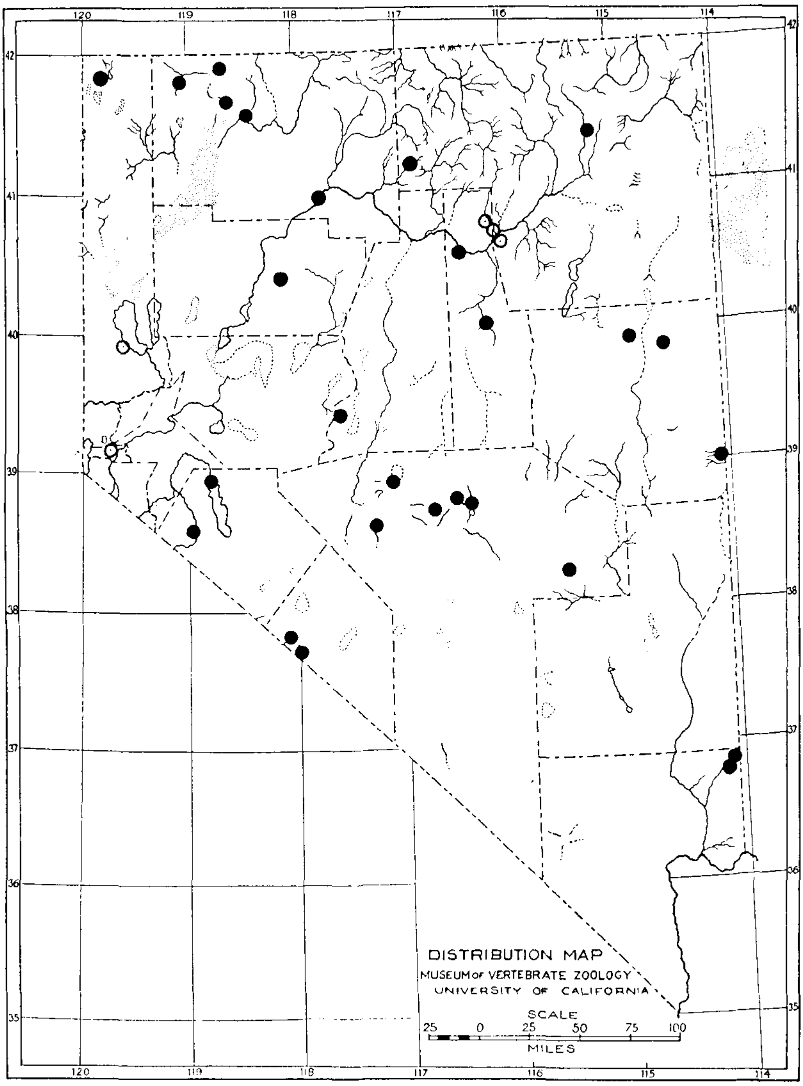
Pershing County: 2 miles east of Unionville (Mus. Vert. Zool.).

Lander County: Smith Creek (Mus. Vert. Zool.).

Eureka County: 5 miles north of Beowawe (Mus. Vert. Zool.); Winzell (Mus. Vert. Zool.).

White Pine County: Cherry Creek (Mus. Vert. Zool.); east side of Schellbourne Pass (Mus. Vert. Zool.); 2½ miles east of Baker (Mus. Vert. Zool.).

Mineral County: East Walker River, 2 miles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DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
25 0 25 50 75 100
MILES

FIG. 1. Distribution of *Scaphiopus hammondii* in Nevada. Solid figures indicate specimens in Museum of Vertebrate Zoology; open figures indicate other records.

northwest of Morgans Ranch (Mus. Vert. Zool.); 3 miles south of Schurz, on Walker Lake (Mus. Vert. Zool.).

Esmeralda County: Arlemont (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.).

Nye County: Smoky Valley, 4 to 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); 7 miles north of San Antonio (Mus. Vert. Zool.); Monitor Valley, 9 miles east of Toquima Peak (Mus. Vert. Zool.); Greenmonster Cañon, Monitor Range (Mus. Vert. Zool.); Fish Spring Valley, 6.5 miles north of Fish Lake (Mus. Vert. Zool.); Burned Corral Cañon, Quinn Cañon Mountains (Mus. Vert. Zool).

Clark County: Bunkerville (Mus. Vert. Zool.); ¼ mile north of Mesquite (Mus. Vert. Zool.).

A specimen from Salt Lake City, Utah, and three or four from Pyramid Lake, Nevada, provided the basis for the description of the species *Scaphiopus intermontanus* by Cope (1883, p. 15). According to him the frontoparietal bones, though ossified, are not roughened in this form as in the other species of *Scaphiopus*. He considered this form nearest to the one from San Antonio, Texas (*S. varius*), from which it differed in having the vomerine teeth between the posterior borders of the internal nares rather than entirely posterior to them. Also the lips are not cross-barred, as they are in *S. varius*, and the superior region has two pale lines on each side, which are replaced by a coarse marbling in *S. varius*. Compared with *hammondii* this form was supposed to be distinguished by larger size, lighter colors, and the presence of the superior pair of light lines.

Nearly 400 specimens of this species in the Museum of Vertebrate Zoology were studied to determine the identity of the Nevada ones. These fall into general groups with characters about as Cope (1889, p. 303) indicated. However, the material is not yet sufficient to make adequate definitions of the groups. The easternmost group is represented by fourteen specimens from a single locality in eastern Colorado. They show remarkable uniformity in the characters which have been ascribed to the form *bombifrons*. The eighteen specimens from southern California are nearly as uniform in opposite development of these characters. They have the features that have been assigned to the form *hammondii*. However, the type locality, Fort Reading, in the northern part of the Sacramento Valley, is about 125 miles north of the nearest locality represented in that lot from southern California. No specimens are available from the northern Sacramento Valley to show whether the population from the southern part of the state is truly *hammondii*.

The rest of the specimens are from scattered western localities between these two extremes, with few adults from any one place. They appear to demonstrate that *bombifrons* and *hammondii* are in the same species, for there is obvious intergradation in every character. Moreover, it seems likely that additional material from this intervening area would demonstrate the validity of a third race, *intermontanus*. In this area the toads are less uniform than either the Colorado or California populations and they are nearer structurally to the latter.

The variable characters in this species change perceptibly with increase in age, thus, to some extent, discounting their usefulness in geographical analysis. Table 1 (p. 200) summarizes some of the variable structural features of specimens in the Museum.

At Pyramid Lake, in 1911, 1912, and 1913, this toad was studied by Snyder (1920, p. 82). The species was seen first from April 23 to 25, and egg-laying was noted from May 28 to June 2. He pointed out that the chorus differed from that of *Hyla* and *Rana*, being in a lower key, somewhat guttural, and a little rasping; also it was entirely different from that of *Bufo*. The animals were collected in numbers in the quiet water of irrigation ditches and in little ponds, where at night they sprawled out motionless in the water, eyes projecting above the surface. All of them disappeared after egg-laying on June 2, 1911. Also at Pyramid Lake, in 1916, Van Denburgh and Slevin (1921, p. 29) from July 3 to 9, obtained fourteen specimens at dusk in pools of water on the beach.

Ruthven and Gaige (1915, p. 15) found this species to be common in the Humboldt Valley, about Carlin. The only adult obtained was found beneath a well curb in Carlin. Near Maggie Creek, on July 4, they collected many small, recently transformed individuals in the dried up bed of an irrigation ditch.

Specimens were obtained by Taylor (1912, p. 345) in Humboldt County, in 1909, on May 30 and June 4 and 21.

BUFONIDAE

Bufo boreas boreas Baird and Girard

Northwestern Toad

Original description.—*Bufo boreas* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, pp. 174–175 (Columbia River and Puget Sound).

TABLE 1

VARIATION IN SPADEFOOT TOADS FROM WESTERN UNITED STATES

Locality	No. of spec.	Internasal width nostril to eye			Pigment on 1st front toe			Interorbital boss			Metatarsal tubercle		
		<	=	>	absent	trace	present	absent	trace	present	long	med.	high
Los Angeles, Tulare, Santa Barbara, Kern, Fresno Cos., Calif.	18	14	1	3	11	7	0	13	5	0	18	0	0
Lassen, Modoc, Plumas, and Mono Cos., Calif.	35	11	11	12	35	0	0	21	13	0	27	6	2
Oregon	2	0	0	2	1	0	1	0	2	0	1	0	1
Washington	2	0	0	2	1	0	1	0	0	2	1	1	0
Idaho	3	0	0	3	2	0	1	0	2	1	1	0	2
Humboldt Co., Nevada	8	4	0	4	7	1	0	2	4	1	3	3	2
Mineral, Esmeralda Cos., Nevada	15	2	4	7	8	4	3	6	6	1	9	5	1
Lander Co., Nevada	1	0	0	1	1	0	0	0	0	1	0	0	1
Nye Co. (adults)	17	3	2	12	8	1	8	1	15	1	8	4	5
Nye Co. (young)	263	160	79	24	257	5	1	112	149	0	183	53	6
White Pine Co., Nevada	3	0	0	3	2	0	1	0	0	3	1	1	1
Elko Co., Nevada	2	2	0	0	0	1	1	0	2	0	1	1	0
Clark Co., Nevada	2	0	0	2	1	0	1	0	1	1	2	0	0
Utah	1	0	1	0	1	0	0	0	1	0	1	0	0
Colorado	14	0	0	14	5	0	9	0	0	14	0	0	14
Arizona	5	0	0	5	0	2	3	0	2	3	1	1	3
New Mexico	1	0	0	1	1	0	0	0	0	1	1	0	0

Synonyms for Nevada.—*Bufo columbiensis*, Cope, 1889, p. 271.

Bufo boreas, Ruthven and Gaige, 1915, p. 13.
Bufo boreas halophilus, Slevin, 1928, p. 96.

Range.—This race extends from southern Alaska south to central California and eastward in the United States to Colorado.

Occurrence in Nevada.—Rather generally distributed in the northern half of the state south to about the 39th parallel; extends beyond this line at least in Smoky Valley. Limited closely to near vicinity of streams, but otherwise wide-ranging. Has been captured at altitudes from near 4,000 feet to over 9,000 feet.

Nevada localities (Fig. 2) (163 specimens in Museum of Vertebrate Zoology).—

Washoe County: Rock Creek, 7,000 feet, Granite Mountains (Mus. Vert. Zool.); 4 miles south of Flanigan, 4,100 feet (Mus. Vert. Zool.); Sutcliffe (Van Denburgh and Slevin, 1921, p. 29); The Pyramids (Van Denburgh and Slevin, 1921, p. 29); Anaho Island, Pyramid Lake (Calif. Acad. Sci); Verdi (Mus. Vert. Zool.); Reno (Mus. Vert. Zool.); Galena Creek (Mus. Vert. Zool.); 3 miles south of Mount Rose, 8,500 feet (Mus. Vert. Zool.); Incline (Mus. Vert. Zool.).

Storey County: Virginia City (U. S. N. M.).

Ormsby County: Carson City (U. S. N. M.).

Douglas County: Glenbrook (Calif. Acad. Sci.; U. S. N. M.).

Humboldt County: Alder Creek (Mus. Vert. Zool.); Leonard Creek (Mus. Vert. Zool.); Big Creek Ranch (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); Martin Creek R. S., Santa Rosa Mountains (Mus. Vert. Zool.).

Elko County: Mountain City (U. S. N. M.); Cobb Creek, 6 miles southwest of Mountain City (Mus. Vert. Zool.); Marys River, 22 miles north of Deeth (Mus. Vert. Zool.); 5 miles northwest of Deep Creek (Mus. Vert. Zool.); Elko (Calif. Acad. Sci.); Wells (U. S. N. M.); Upper Humboldt Valley (U. S. N. M.); Summit Secret Pass (Mus. Vert. Zool.); Jerry Creek (Mus. Vert. Zool.); head of Ackler Creek (Mus. Vert. Zool.); west side of Ruby Lake (Mus. Vert. Zool.); South Fork of Long Creek (Mus. Vert. Zool.); Three Lakes (Mus. Vert. Zool.); Harrison Pass R. S. (Mus. Vert. Zool.); 3 miles south of Halleck (U. S. N. M.); James Creek (Univ. Mich.); Maggie Creek (Univ. Mich.); Moleen Cañon (Univ. Mich.); 10 and 11 miles southwest of Midas (Mus. Vert. Zool.).

Lander County: Reese River Valley, 7 miles north of Austin (Mus. Vert. Zool.); Austin (U. S. N. M.); Big Creek (Mus. Vert. Zool.); Kingston R. S. (Mus. Vert. Zool.).
Eureka County: Evans (Mus. Vert. Zool.); 4 miles south of Romano, Diamond Valley (Mus. Vert. Zool.); Winzer (Mus. Vert. Zool.).
White Pine County: Willow Creek, 2 miles south of county line (Mus. Vert. Zool.).
Esmeralda County: Fish Lake (Mus. Vert. Zool.).
Nye County: 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); South Twin River, 6,000 feet (Mus. Vert. Zool.); 1½ miles south of Darrough's, 5,700 feet (Mus. Vert. Zool.); 7 miles north of San Antonio (Mus. Vert. Zool.).

Around the southern margin of the range of this species, in the dry areas in California and Nevada, are several populations or groups of populations that are segregated from one another by desert land which has no suitable habitat for this kind of toad. Some of these populations have been distinguished and named by naturalists, but the field work in this district has not been sufficient to clarify the taxonomic relations of all the colonies. No final treatment can be given the species now, but it seems clear that at least the races *halophilus* and *nelsoni* deserve recognition in southern California and Nevada.

The greatest uncertainty remains with respect to the toads in the vicinity of Walker Lake in western Nevada, which are here assigned to *B. b. halophilus*, but which seem to have no direct geographic connection with that race. Then, the sixteen specimens from Fish Lake Valley appear to represent an extreme of development of characters which can be detected in the southern Sierra Nevada. The most striking feature of coloration in this lot is the heavily spotted throat possessed by all those from Fish Lake Valley. This character is shown by only one of a large series of *B. b. boreas* from Humboldt County, Nevada. Apparently the Fish Lake Valley toads do not reach a large size; the largest one is only 80 mm. in head and body length.

Mention of occurrence of *B. woodhousii* in Humboldt County, Nevada, in various publications (Taylor, 1912, p. 344; Kellogg, 1932, p. 72) apparently is based on specimens of *Bufo boreas boreas* in the Museum of Vertebrate Zoology.

In the vicinity of the Pine Forest Mountains, Humboldt County, Taylor (1912, pp. 343–345) found toads at levels between 4,100 and 8,500 feet. In the mountains they were present in the meadows and small lakes. At lower altitudes they were obtained along the streams; none being found more than fifteen feet from running water. One tried to escape by swimming to the bottom of a stream where it remained for several minutes. Usually, when pursued, they left the water and tried to escape over land. A mating pair was observed at 4,350 feet on June 9, and tadpoles were observed on May 24 and August 7.

Ruthven and Gaige (1915, p. 13) found this species to be abundant in the upper Humboldt Valley. Several females found on July 16, in dense grass at the edge of ditches, contained eggs. The toads were tame and usually walked rather than hopped. Stomachs contained ants and beetles. Tadpoles were abundant and in late July the trails in James Cañon were covered with recently transformed individuals. These authors report eight out of eleven adult toads having distinctly oval ear patches. Length of leg to heel was less than the distance to arm insertion by half an inch or equal to the distance to the rear end of the parotoids. The color was a dull brownish gray, with a broad light vertebral stripe, a patch of light color beneath the eye, a conspicuous black blotch between the thighs on the ventral surface, and with the tubercles on the fingers and toes tipped with orange.

Bufo boreas halophilus Baird and Girard

California Toad

Original description.—*Bufo halophila* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1853, p. 301 (Benicia, Solano County, California).

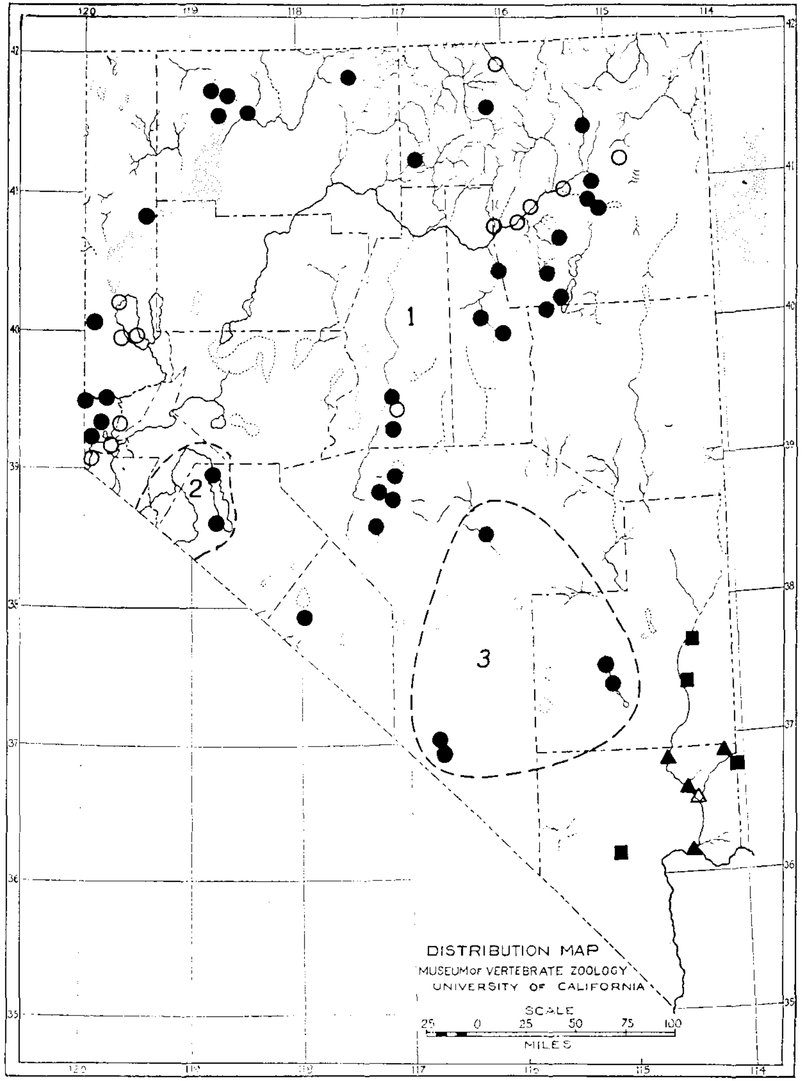
Range.—Lower parts of central and southern California, south to northern Lower California and eastward to Nevada.

Occurrence in Nevada.—Recorded from several localities in the vicinity of Walker Lake in west-central part of the state. Whether this population is connected with the main range of the race in California or is isolated from it cannot be determined from the material now available.

Nevada localities (Fig. 2) (50 specimens in Museum of Vertebrate Zoology).—

Mineral County: 3 miles south of Schurz (Mus. Vert. Zool.); Cottonwood Creek (Mus. Vert. Zool.).

In a series of 31 specimens from 3 miles south of Schurz on Walker Lake, Mineral County, 12 are unspotted below, 11 are faintly speckled with small dark spots, and 8 are thickly dotted with small dark spots. In each individual of this series the knees and elbows meet or overlap when


DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
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MILES
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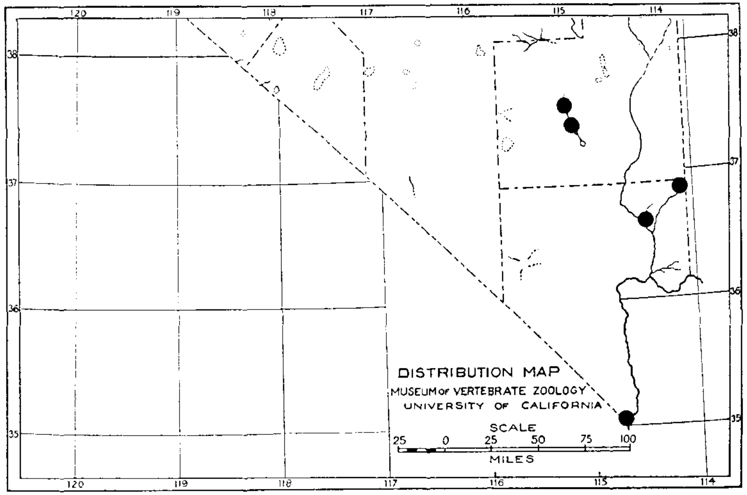
Fig. 2. Distribution of *Bufo boreas* (circles) in Nevada (1, *B. b. boreas*; 2, *B. b. halophilus*; 3, *B. b. nelsoni*), *Bufo compactilis* (squares) and *Bufo woodhousii* (triangles).


DISTRIBUTION MAP
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UNIVERSITY OF CALIFORNIA
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Fig. 3. Distribution of *Bufo cognatus* in southern Nevada.

adpressed to the side of the body. Compared with the toads from the Amargosa River these have distinctly wider and more blunt heads. The tubercles on the backs are rougher and more prominent in the Walker Lake specimens.

Bufo boreas nelsoni Stejneger

Amargosa Toad

Original description.—*Bufo boreas nelsoni* Stejneger, N. Amer. Fauna no. 7, 1893, pp. 220–221, pl. 3, figs. 4*a*, 4*b* (Oasis Valley, Nye County, Nevada).

Synonym for Nevada.—*Bufo boreas halophilus*, Slevin, 1928, p. 96.

Range.—Southern and eastern Nye County and northern Lincoln County, Nevada.

Occurrence in Nevada.—So far known from three separated localities, but most characteristic population is in the upper part of the Amargosa River. Apparently this toad is more closely restricted to water than even its near relatives which inhabit morehumid districts. Near Beatty, about May 20, 1931, many small young toads were picked up near the stream; large tadpoles were obtained here on May 4, 1936.

Nevada localities (Fig. 2) (60 specimens in Museum of Vertebrate Zoology).—

Nye County: Springdale, north end Oasis Valley (Mus. Vert. Zool.); Oasis Valley (U. S. N. M.); Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.); Hot Creek Valley, 5,900 feet (Mus. Vert. Zool.).

Lincoln County: Pahranagat Valley, 3 miles south of Crystal Spring (Mus. Vert. Zool.); 4 miles south of Alamo (Mus. Vert. Zool.).

The characters given by Stejneger (1893, p. 220) in the diagnosis of *Bufo boreas nelsoni* were as follows: "Similar to *B. boreas:* Skin between warts smooth; snout protracted, pointed in profile; webs of hind legs very large; soles rather smooth; limbs shorter, elbows and knees not meeting when adpressed to the sides of the body; inner metacarpal tubercle usually very large."

The 51 specimens now on hand from Oasis Valley and the Amargosa River near Beatty agree with this diagnosis in some features and differ from it in others. They contrast with the toads of the species *Bufo boreas* to the north and west in the following characters.

Small size: the largest adult in the lot measures 72.5 mm. in head and body length. This is a little more than half the maximum size of *Bufo b. boreas*.

The narrow, wedge-shaped head, especially when viewed from below, is one of the striking peculiarities of this toad. This seems to be correlated with the snout protracted and pointed in profile as mentioned by Stegneger.

Limbs so reduced that when adpressed to sides of body elbows and knees do not meet as was pointed out by Stejneger.

Small feet and reduced webbing is especially noticeable and is just the reverse of Stejneger's statement which may not have been as he intended.

Reduced spots below in all the large individuals contrasts with *boreas* and with all small ones from the Amargosa Valley. Possibly the old ones tend to lose ventral spotting.

Smooth skin and small, weakly developed, warts which characterize this lot may be an indication of close restriction of these toads to the water.

Inner metacarpal tubercle appears to average large, as Stejneger indicated.

Specimens from two other localities in southern Nevada, Hot Creek Valley and Pahranagat Valley, seem to be nearer to this form than to any other, but the few available from there appear to vary towards *B. b. boreas.*

I conclude that *B. b. nelsoni* is a well-marked subspecies developed almost to the point of being a distinct species and that it is most closely related to the race *boreas* which comes near it on the north. This population is on the margin of the range of the species and shows extreme development of its characters. These characters are not modified in the direction of *halophilus* which also occurs to the south of *boreas*, but typically on the lower ground nearer the Pacific coast.

Bufo cognatus Say

Great Plains Toad

Original description.—*Bufo cognatus* Say, in Long, Account of an expedition from Pittsburgh to the Rocky Mountains, vol. 2, 1823, p. 190 (Arkansas River, Prowers County, Colorado).

Synonym for Nevada.—*Bufo lentiginosus woodhousii*, Stejneger, 1893, p. 221.

Range.—Montana east to North Dakota and south to southeastern California and into Mexico.

Occurrence in Nevada.—The known localities of capture are in the southeastern part of the state, south of 38° N. and east of 116° W. Specimens in Mus. Vert. Zool. were taken in May.

Nevada localities (Fig. 3) (97 specimens in Museum of Vertebrate Zoology).—

Lincoln County: Crystal Spring, and 1 and 3 miles north, 4,000 feet, Pahranagat Valley (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); 4 miles south of Alamo (Mus. Vert. Zool.).

Clark County: Mesquite, west of Virgin River, 1,950 feet (Linsdale, MS); 2 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); Colorado River, opposite Fort Mojave (Mus. Vert. Zool.).

Sixty-one specimens of *Bufo cognatus* were obtained, May 16 to 24, 1932, by a party of collectors from the Museum of Vertebrate Zoology, at the north end of Pahranagat Valley, Lincoln County, in the vicinity of Crystal Spring. One of these collectors (Fitch, MS) made notes from which the following items were obtained: At Crystal Spring, on May 15, a large toad was captured just before dusk along the edge of the shallow lake two hundred yards north of the camp. At 8:30 p. m., after dark, search was begun with flashlights for amphibians in an alfalfa field between camp and the lake. None was found in the dry part of the field. Crickets were chirping in the field, but when the persons came near the edge of the water, they recognized that a part of the chorus was made by the toads. They searched for several rods along the shore and found two toads, but most of the animals were out in the water. More than twenty toads were captured within fifteen minutes, and nearly all those found in the water were males. They were found within a patch of tules, clinging to the stems, where water was up to eighteen inches deep. The body was held at right angles with the surface of the water and only the head projected above the surface. They usually stopped croaking when the light was brought near.

On the evening of May 17, the chorus began after dark at about 8 p. m. An hour later one toad was found in the camp and a five minute search along the dry bottom of an irrigation ditch close by and two hundred yards from the water yielded fourteen toads of which only two possessed the dark throat patches which characterize the males at this season. It was not apparent that they were moving toward the water; rather they seemed to be foraging. After one was killed, an insect larva which it had just caught was noticed in its mouth. Since only a few females, and no mating pairs, had been found in the water on the previous night, it seemed evident that most of the females had not yet gone to the water.

Bufo compactilis Wiegmann

Sonoran Toad

Original description.—*Bufo compactilis* Wiegmann, Isis von Oken, vol. 26, pt. 7, 1833, p. 661 (Mexico).

Synonym for Nevada.—*Bufo lentiginosus woodhousii* Stejneger, 1893, p. 221.

Range.—In the United States from southern Nevada and Utah east to southeastern Oklahoma and south to the states of Michoacan and Tabasco in Mexico.

Occurrence in Nevada.—The known localities of occurrence are in the southeastern part of the state, in Meadow Valley, in the Virgin Mountains, and near Las Vegas. They range in altitude from 2,000 to 4,500 feet. Earliest date of capture was on March 23 (1923) at Las Vegas; others are in mid-June, August and October 9 (1913).

Nevada localities (Fig. 2) (30 specimens in Museum of Vertebrate Zoology).—

Lincoln County: Caliente (Calif. Acad. Sci.); Kershaw Cañon-Ryan State Park, 1 mile south of Caliente (Mus. Vert. Zool.); 7 and 21 miles south of Caliente (Mus. Vert. Zool.).

Clark County: Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); Las Vegas (Mus. Vert. Zool.; Calif. Acad. Sci.); Vegas Valley (U. S. N. M.).

Wright and Wright (1933, pp. 60–61) wrote of *Bufo compactilis*, as follows:

"Range: Southern portions of Utah and Nevada south far into Mexico, and east to Oklahoma and the eastern timber belt of Texas.

"Habitat: We found this toad breeding in rain pools in open fields near streams, in pools in creek valleys, in irrigation tanks or cattle tanks. It is a desert form that may at times be seen feeding at night under the street lights of desert towns.

"Size: Adults, 2 1/12–3 5/8 inches. (Males, 52–78 mm. Females, 54–91 mm.).

"General appearance: This broad, 'squatty' toad of medium size is pinkish drab in color, marked with dull citrine spots. The fingers and toes are light in color. The under parts are light. The back is covered with light tipped tubercles. In the male, the tip of the chin is white, then the folded part of the throat is pinkish buff with ecru-olive in the center. This area is followed by a circular pectoral area of purplish lilac.

"Structure: Parotoid, elongate, sometimes smooth; no sharp-edged ridge from eye to nostril, nostril area smooth; crown without bony ridges;

snout short, blunt; interorbital space about equal to upper eyelid; first finger at least equal to second; toes half webbed; sole tubercles large, each with a cutting edge; tympanum much smaller than the eye.

"Voice: The vocal sac is a large fat oblong 'sausage.' Deflated it forms a light apron covering several darker folds in the rear of the throat. The call is loud and shrill, a trill.

"Breeding: They breed from May 1 to July 10, or a few stragglers later, with the late summer rains. The brown and yellow eggs are in long fine coils, the jelly tube narrow, 1/12 inch (2 mm.), the eggs crowded, 14–20 eggs in 1 1/5 inches (30 mm.), the vitelli 1/16 inch (1.4 mm.). They hatch in 2 days. The bicolored tadpole is small, 1–1 1/8 inches (24–28 mm.), light colored, its back a drab or light grayish olive; its belly, pale cinnamon pink; its tail crests translucent. The tooth ridges are 2/3. After a tadpole period of 40 to 60 days, they transform, June 1 to August 1, at ½ inch (12 mm.)."

Selected differences between *woodhousii* and *compactilis* in typical form are indicated in the following tabulation of characters.

woodhousii	*compactilis*
Light vertebral streak.	No light vertebral streak.
Upper parts grayish or dull yellowish brown, blotched with a darker color or with scattered spots.	Upper parts light greenish gray or brown, irregularly spotted with darker color.
Cranial crests distinct, but not high.	Cranial crests absent, or poorly defined.
Parotoid glands twice as long as broad.	Parotoid glands reniform.
Tarsal fold indistinct or absent.	Tarsal fold present.
Head-and-body length 80–115 mm.	Head-and-body length 60–87 mm.

The relationships of *B. compactilis* to *B. woodhousii* in southern Nevada are difficult to interpret. The preserved specimens are not quite sufficient and there has been no opportunity to make a thorough study in the field. All the toads from Meadow Valley Wash, Indian Spring in the Virgin Mountains, and Vegas Valley agree fairly well with descriptions of *compactilis* and they are rather uniform structurally. Their occurrence in three far-separated places seems to suggest that the species moved into the region when it was more humid than it is now. These localities are on the northwestern boundary of the range of the species. There would be little question concerning their identification except for the toads in the immediate vicinity of the Virgin and Colorado rivers. These show perceptible traces of *compactilis* characters, but they are here considered as belonging to the form *woodhousii* and their status is discussed under that heading.

The toads here considered as *compactilis*, from southern Nevada and Zion Cañon, Utah, have been compared with a small series (17 specimens) of *B. californicus* from southern California and Lower California. I can see no differences in structure between these series. In coloration they seem to differ in slight degree—the dark dorsal spots on the California ones being a little more distinct and larger. Moreover, the four preserved specimens from Las Vegas differ from the other Nevada ones to a greater degree in the opposite direction, being marked dorsally by very small, fine dark spots.

Geographically the gap between the Nevada and California specimens is not much greater than some of the gaps within the range commonly ascribed to *compactilis*. Apparently the Nevada toads deserve no greater than subspecific distinction from the California ones, if indeed they should not be treated as of the same race. The toads from Las Vegas appear more deserving of subspecific distinction.

A possible differing character is the shape of the inflated vocal sac. Myers (1930, p. 74) reports this as rounded in *californicus*. Both Dickerson (1906, fig. 96) and the Wrights (1933, p. 60) picture *compactilis* with an elongated, kidney-shaped vocal sac. No observations have been made to determine this character in the Nevada toads.

It is necessary, in making final taxonomic appraisal of toads, to study the living animals in their natural surroundings. Until further field studies can be made on this group of forms, satisfactory conclusions cannot be reached. However, the preserved material is sufficient to show that some changes in systematic treatment of the group will be required. Present indications are that these toads are all in the same species. The oldest name in the lot is *compactilis*. At least four races seem to deserve recognition, as follows:

Bufo compactilis compactilis Wiegmann 1833
Bufo compactilis woodhousii Girard 1856
Bufo compactilis fowleri Hinckley 1882
Bufo compactilis californicus Camp 1915

Bufo punctatus Baird and Girard

Red-spotted Toad

Original description.—*Bufo punctatus* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 173 (Rio San Pedro, tributary of the Rio Grande del Norte = Devils River, Val Verde County, Texas).

Range.—Southeastern California and southwestern Utah, east to western Oklahoma and Texas, and south through Lower California and Mexico to San Luis Potosi and Guanajuato.

Occurrence in Nevada.—Found in April, 1936, along the Virgin River near Mesquite, in the Virgin Mountains, and in the Dead Mountains. The toads came after dark to springs and streams, sometimes when there was very little water. Daylight hours were spent in concealment, often in crevices in granite rocks. In the vicinity of Boulder Dam, individuals were found in the summer, of 1935, clinging to driftwood in the reservoir (Cowles and Bogert, 1936, p. 36).

Nevada localities (Fig. 4) (55 specimens in Museum of Vertebrate Zoology).—

Clark County: Virgin Springs, 2,000 feet, 8 miles north of Moapa (Mus. Vert. Zool.); Virgin River, 1 mile southwest of Mesquite, 1,500 feet (Mus. Vert. Zool.); Cabin Creek, 4,500 feet, Virgin Mountains (Mus. Vert. Zool.); Bitter Spring, Virgin Mountains (Mus. Vert. Zool.); Rogers Spring, 2,000 feet, 10 miles southwest of Overton (Mus. Vert. Zool.); Colorado River at mouth of Boulder Wash (Cowles and Bogert, 1936, p. 36); Hiko Spring, 2,000 feet, Dead Mountains (Mus. Vert. Zool.).

Bufo woodhousii Girard

Rocky Mountain Toad

Original description.—*Bufo woodhousii* Girard, Proc. Acad. Nat. Sci. Phila., **7**, 1854, p. 86 ("New Mexico" [San Francisco Mountain, Coconino County, Arizona]).

Synonyms for Nevada.—*Bufo lentiginosus woodhousei*, Cope, 1889, p. 284.

Bufo lentiginosus subspecies *frontosus*, Yarrow, 1875, p. 520.

Bufo woodhousii woodhousii, Cowles and Bogert, 1936, p. 36.

Range.—Western United States and Mexico from Idaho east to the Missouri River and south to Sonora and southern Chihuahua.

Occurrence in Nevada.—Records are all in the southeastern part of the state, in the immediate vicinity of the Virgin and Colorado rivers. Altitudinally, the localities range from about 1,000 feet up nearly to 2,000 feet.

Nevada localities (Fig. 2) (94 specimens in Museum of Vertebrate Zoology).—

Clark County: Warm Springs, 2,000 feet, 8 miles north of Moapa (Mus. Vert. Zool.); Mesquite (Mus. Vert. Zool.; San Diego Soc. Nat. Hist.; Cowles and Bogert, 1936, p. 36); Bunkerville (Mus. Vert. Zool.); 2 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); Kaolin Reservoir (Mus. Vert. Zool.); Saint Thomas (U. S. N. M.); Colorado River, 25 miles above Boulder Dam (Mus. Vert. Zool.); near mouth of Virgin River (Mus. Vert. Zool.).

Occurrence of this species has been attributed to northwestern Nevada by Taylor (1912, p. 342) and Kellogg (1932, p. 72) apparently on basis of specimens of *B. b. boreas* in the Museum of Vertebrate Zoology. The two specimens reported as this species by Stone (1911, p. 223) from Caliente, Lincoln County, are like specimens from farther south in the same valley and now in the Museum of Vertebrate Zoology. These have been included with *Bufo compactilis* in the present report. Also I have examined the two specimens (nos. 18,717–18, U. S. N. M.) taken March 13 and 14, 1893, in Vegas Valley, Clark County, and listed under *woodhousii* by Stejneger (1893, p. 221) and have included them with *B. compactilis.* The other toad listed by Stejneger (*loc. cit.*), taken on May 25, 1891, in Pahranagat Valley, Lincoln County, resembles individuals in the large series from that vicinity which I have identified as *B. cognatus.*

Toads in the Muddy River Valley, along the Virgin River, and a little below the mouth of that river in the Colorado are nearest to *B. woodhousii* as it is represented in other parts of western United States, but they show some characters approaching *B. compactilis.* Size averages small as in the latter species. The light vertebral streak is indistinct in some specimens; the parotoid glands are shorter in some individuals than in normal *woodhousii;* cranial crests are poorly developed in some specimens. The population of toads in this area thus exhibits a wider range of variability than either *compactilis* or *woodhousii* in other regions. Characters of both species are represented but they seem to be predominantly *woodhousii.*

HYLIDAE

Hyla regilla Baird and Girard

Pacific Tree-toad

Original description.—*Hyla regilla* Baird and Girard, Proc. Acad. Nat. Sci. Phila., **6**, 1852, p. 174 (Sacramento River [California], in Oregon and Puget Sound).

Synonyms for Nevada.—*Chorophilus triseriatus*, Stone, 1911, p. 224.
Pseudacris triseriata, Slevin, 1928, p. 120.

Range.—From southern British Columbia east to Idaho and Utah and south to northern Lower California and Arizona.

Occurrence in Nevada.—Apparently the tree-toad ranges over the whole state, but records indicate it is present at only scattered localities. Records are from both the valleys and the mountains; one is as high as 9,300 feet.

Nevada localities (Fig. 4) (208 specimens in Museum of Vertebrate Zoology).—

Washoe County: ½ mile north of Vya, 6,000 feet (Mus. Vert. Zool.); Little High Rock Cañon (Mus. Vert. Zool.); Rock Creek, 7,425 feet, Granite Mountains (Mus. Vert. Zool.); Deephole (Mus. Vert. Zool.); 4½ miles south of Flanigan, 4,100 feet (Mus. Vert. Zool.); Truckee River, 4,900 feet, near Verdi (Mus. Vert. Zool.); 5½ miles north of Incline, 9,300 feet (Mus. Vert. Zool.).

Ormsby County: Carson City (U. S. N. M.).

Humboldt County: Virgin Valley (Mus. Vert. Zool.); Pine Forest Mountains (Mus. Vert. Zool.).

Elko County: Jarbidge Mountains (Mus. Vert. Zool.); James Creek and Carlin Peaks, Cortez Mountains (Univ. Mich. Mus.); 10 and 11 miles southwest of Midas (Mus. Vert. Zool.).

Eureka County: Eureka (Slevin, 1928, p. 116).

Nye County: Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.); 1 mile southeast of Beatty (Mus. Vert. Zool.); Oasis Valley (U. S. N. M.); Ash Meadows (U. S. N. M.); Pahrump Valley (Slevin, 1928, p. 116).

Clark County: Cottonwood Springs and Mountain Spring, Charleston Mountains (U. S. N. M.); Younts Ranch, Pahrump Valley (U. S. N. M.); Corn Creek (U. S. N. M.); Las Vegas (Mus. Vert. Zool.; Calif. Acad. Sci.); Vegas Valley, 1,800 feet (U. S. N. M.).

Tree-toads captured on September 2, 1909, at Las Vegas, Nevada, were reported by Stone (1911, p. 224) as *Chorophilus triseriatus*. Later lists have included this species from Nevada under the name *Pseudacris triseriata* apparently on the basis of this record. In response to an enquiry about the three specimens (nos. 17,876–78, Acad. Nat. Sci. Phila.), H. W. Fowler wrote to me on March 5, 1936, that he had been unable to locate them in the collection. Since the identification cannot be verified and the locality is far from the nearest other record stations for the species in northeastern Utah and central Arizona, it seems best to have further evidence before accepting this as a Nevada species.

In Elko County, tree-toads were collected in James Cañon by Ruthven and Gaige (1915, p. 14). Early in August many partly grown ones were found under stones and in sagebrush around two small ponds. Two adults were obtained in rock slides on Carlin Peaks, one near a spring and the other several miles from water.

Taylor (1912, p. 343) on July 31, 1909, noted tadpoles and young tree-toads in a lake at Duffer Peak Meadow, 8,400 feet, in the Pine Forest Mountains, Humboldt County.

RANIDAE

Rana aurora draytonii Baird and Girard

Red-legged Frog

Original description.—*Rana Draytonii* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 174 (San Francisco, California).

Range.—This race occupies a narrow strip of land next to the Pacific coast from near Mendocino City, Mendocino County, California, south to the Santo Domingo River, Lower California.

Occurrence in Nevada.—Known only from certain springs on the floor of Smoky Valley, 5,500 feet, Nye County, in the center of the state, where according to local testimony individuals of this frog brought from California were liberated several years ago by a Mr. Gendron who still lives in the valley.

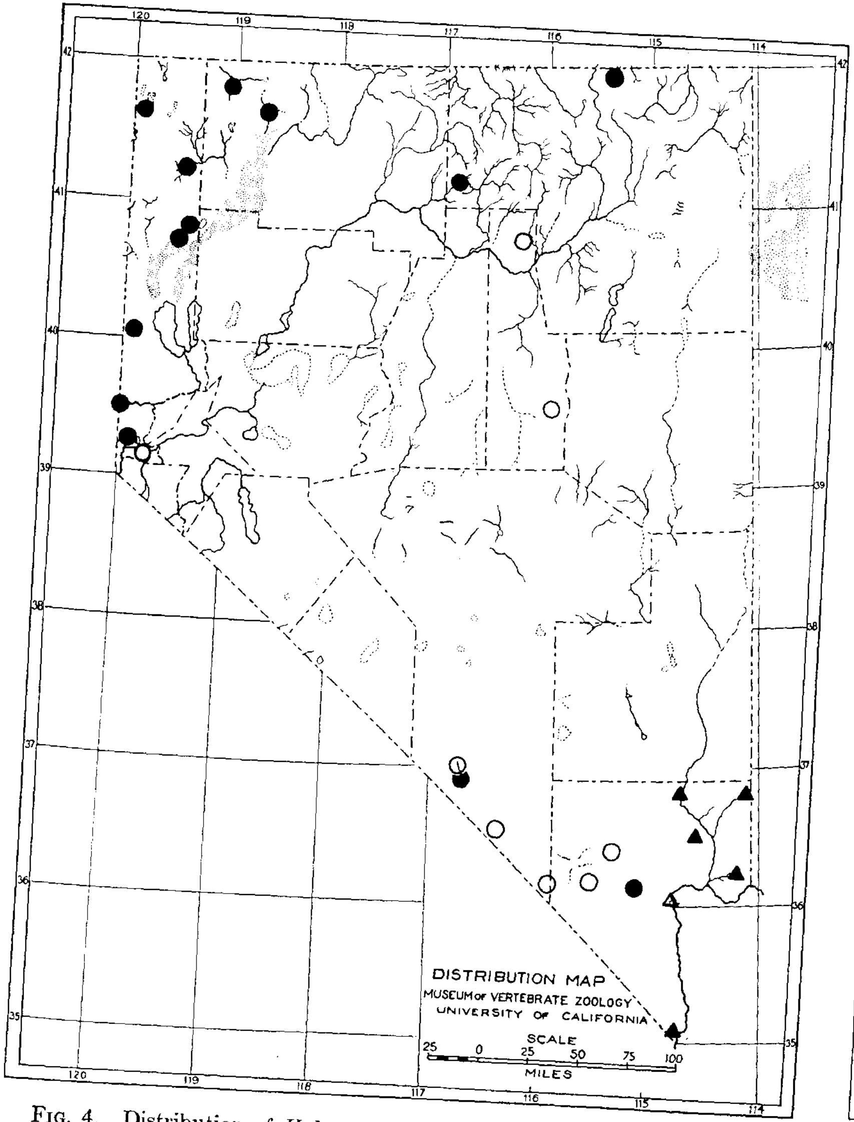
Nevada locality (1 specimen in Museum of Vertebrate Zoology).—

Nye County: Millett P. O. (Mus. Vert. Zool.).

Rana boylii sierrae Camp

Sierra Nevada Yellow-legged Frog

Original description.—*Rana boylii sierrae* Camp, Univ. Calif. Publ. Zool., vol. 17, 1917, p. 120 (Matlack Lake, 10,500 feet, 2 miles south of Kearsarge Pass, Inyo County, California).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UNIVERSITY OF CALIFORNIA
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FIG. 4. Distribution of *Hyla regilla* (circles) and *Bufo punctatus* (triangles) in Nevada.

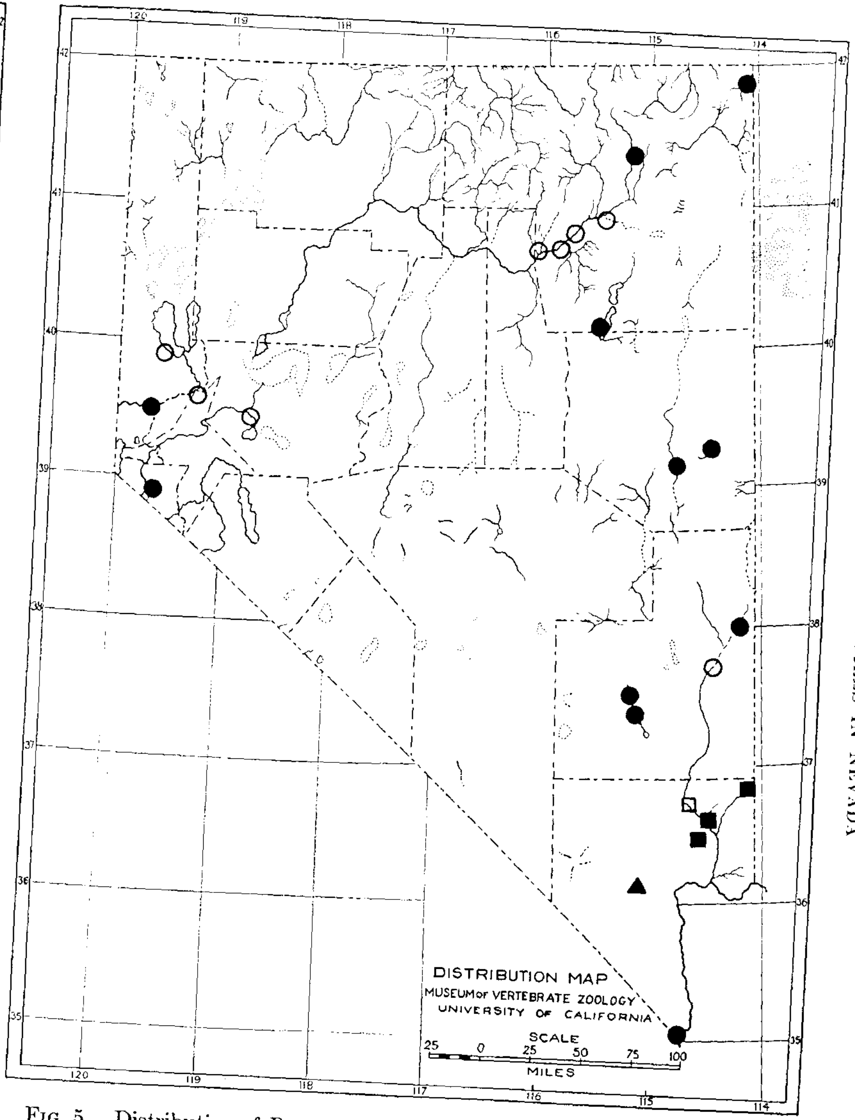
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FIG. 5. Distribution of *Rana pipiens* (circles), *Rana onca* (squares), and *Rana fisheri* (triangle) in Nevada.

Synonyms for Nevada.—*Rana pretiosa*, Slevin, 1928, p. 136.
Rana temporaria pretiosa, Cope, 1889, p. 434.

Range.—Occurs only on the high parts of the central and southern Sierra Nevada, mainly in California.

Occurrence in Nevada.—Has been collected in the vicinity of Lake Tahoe and northward on the slopes of Mount Rose. Records range from 6,300 feet to 9,300 feet and, seasonally, from June 12 to August 21. The frogs were found along small streams and in small shallow lakes in meadows.

Nevada localities (18 specimens in Museum of Vertebrate Zoology).—

Washoe County: 5½ miles north of Incline, 9,300 feet, and Incline, at north end of Lake Tahoe (Mus. Vert. Zool.); 3 miles south of Mount Rose, 8,500 feet (Mus. Vert. Zool.); Lake Tahoe (U. S. N. M.).

Four specimens in U. S. N. M. from Lake Tahoe and evidently the basis for record of *Rana pretiosa* from that locality (see Slevin, 1928, p. 136) were examined by me on November 7, 1933. I identified them as *R. b. sierrae*.

Rana catesbeiana Shaw

Bullfrog

Original description.—*Rana catesbeiana* Shaw, Gen. Zool., vol. 3, pt. 1, 1802, p. 106, pl. 33 (South Carolina).

Range.—Originally North America east of Rocky Mountains from southern Canada to northern Mexico. Has been transplanted to many localities in western United States.

Occurrence in Nevada.—Introduced at Ash Meadows, 2,173 feet, where a specimen was obtained on May 20, 1933, by W. C. Russell, and another on May 3, 1936 (Linsdale). One was heard on April 26, 1936, at Kaolin Reservoir, Clark County (Linsdale, MS).

Nevada locality (2 specimens in Museum of Vertebrate Zoology).—

Nye County: Ash Meadows (Mus. Vert. Zool.).

Rana fisheri Stejneger

Nevada Frog

Original description.—*Rana fisheri* Stejneger, N. Amer. Fauna no. 7, 1893, p. 227 (Vegas Valley, Clark County, Nevada).

Synonym for Nevada.—*Rana onca*, Slevin, 1929, p. 127.

Range.—Known only from the vicinity of Las Vegas, Vegas Valley, Clark County, Nevada.

Occurrence in Nevada.—Inhabits the springs and short streams in the near vicinity of Las Vegas, close to 2,000 feet elevation. These frogs are most active in spring and early summer; dates of capture range from early in March to August 13.

Nevada localities (Fig. 5) (17 specimens in Museum of Vertebrate Zoology).—

Clark County: vicinity of Las Vegas (Mus. Vert. Zool.; Calif. Acad. Sci.; U. S. N. M.).

Stejneger (1893, p. 227) described *Rana fisheri* from Vegas Valley, Nevada, as follows: "Heel of extended hind limb reaching anterior eye canthus, falling considerably short of tip of snout; vomerine teeth between and projecting posteriorly beyond choanae; no black ear patch; vertical diameter of tympanic disc greater than distance between nostrils and eye; hind feet webbed for about two-thirds; one small metatarsal tubercle; one weak dorso-lateral dermal fold, no dorsal folds between; posterior lower aspect of femur granular; back and sides with numerous small, distinct, dark spots, surrounded by lighter; no external vocal sacs." He added that "the great size of the tympanic disc is also quite characteristic, being larger than in any of our species, except *R. catesbiana, clamitans,* and *septentrionalis*."

For many years this form has been considered a synonym of *Rana onca* which was known from the single type specimen obtained by Yarrow in 1872 in "Utah." So few specimens have been available from southern Utah and southern Nevada that the relationships of the frogs in that area could not be studied satisfactorily. With the series now available from this region along with a study of the physiography of the area, I have been able to come to conclusions as follows: The population of frogs in Vegas Valley is sharply isolated from the closely related ones in the Colorado and Virgin river valleys. Although other colonies of *Rana* are isolated in eastern and southern Nevada, they have become less markedly differentiated from the common type of southwestern *Rana pipiens*. Whether the frogs of southern Utah and Nevada need separate recognition under the name *onca* as a species or subspecies cannot be determined without a study of the whole species throughout its range, but it seems plain to me that the Vegas Valley ones should be recognized as distinct. Although entered here as a species, this form is obviously closely related to *Rana pipiens* and it might well be known as a race of that species. It contrasts most sharply with that frog in its peculiar shade of ground color, the reduction of dorsal spots, especially on the head, the enlarged tympanum, and in the reduced hind legs.

Rana onca Cope

Nevada Frog

Original description.—*Rana onca* Cope, in Yarrow, Rept. Geog. and Geol. Expl. and Surv. west of 100th mer. (= Wheeler Survey), vol. 5, Zool., 1875, p. 528, pl. 25, figs. 1–3 (Utah).

Range.—Known only from the vicinity of the Virgin River in southern Nevada and Utah.

Occurrence in Nevada.—Inhabits streams and springs in southeastern part of the state; localities are along the Virgin and Lower Muddy rivers. They range in altitude from about 1,200 feet up to around 2,000 feet.

Nevada localities (Fig. 5) (78 specimens in Museum of Vertebrate Zoology).—

Clark County: Virgin River, 1,500 feet, near Mesquite (Mus. Vert. Zool.); Glendale (U. C. L. A.); 2 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); Rogers Spring, 2,000 feet, 10 miles southwest of Overton (Mus. Vert. Zool.).

According to Tanner (1931, p. 189) *Rana onca* differs from *R. pipiens* "in having no definite narrow longitudinal folds between the dorsolateral ridges, its smaller size, and habitat in the extreme southwestern corner of Utah along the Virgin River. The head is as broad as long and depressed; the nostrils are nearer the eyes than the end of the snout; canthus rostralis almost absent in the specimens before me. Tympanic membrane large and smooth. The limbs are well developed, digits long and webs well formed. Skin above smooth with a few warts and tubercles about the head and neck.

"The general color above is brown to olive green with spots that are bordered with grey. The noticeable dorso-lateral fold is brown in the specimens examined. The undersurface is white over the belly and yellowish on the legs."

Recently collected series of specimens from several localities near the Virgin River indicate that this form is distinct from both *Rana pipiens* and *Rana fisheri*. From the former it differs by having smaller and fewer spots and these on a paler background and with less distinct gray borders, larger tympanum, and shorter legs. It is nearer to *fisheri* which reaches the extreme development in these characters, having still fewer dorsal spots and much shorter hind legs. The characters of smaller size and absence of longitudinal folds between dorsolateral ridges seem not to be diagnostic in the Nevada material.

Rana pipiens Schreber

Leopard Frog

Original description.—*Rana pipiens* Schreber, Naturforscher, vol. 18, 1782, p. 185, pl. 4 (New York).

Synonyms for Nevada.—*Rana halecina berlandieri*, Yarrow, 1883, p. 181.

Rana virescens brachycephala, Cope, 1889, p. 405.

Range.—Widespread in North America east of the Sierra Nevada and south into Mexico.

Occurrence in Nevada.—Recorded from many lakes and larger streams in the state, mainly in the northern and eastern parts; also present in the immediate vicinity of the Colorado River. Localities of record, outside the Colorado Valley, are mainly at altitudes between 4,000 and 6,000 feet. This is the commonest and most widespread kind of frog in the state.

Nevada localities (Fig. 5) (94 specimens in Museum of Vertebrate Zoology).—

Washoe County: The Willows, Pyramid Lake (Slevin, 1928, p. 125); Truckee River, 4900 feet, near Verdi (Mus. Vert. Zool.); Truckee River, 9½ miles east of Reno (Mus. Vert. Zool.).

Douglas County: Minden (Mus. Vert. Zool.).

Lyon County: Near Fernley (U. S. N. M.); 1 mile southeast of Fernley (Univ. Mich. Mus.).

Elko County: Marys River, 22 miles north of Deeth (Mus. Vert. Zool.); Goose Creek, 5,000 feet (Mus. Vert. Zool.); Humboldt River Valley (Univ. Mich. Mus.); Susan Creek (Univ. Mich. Mus.); Maggie Creek (Univ. Mich. Mus.); Moleen Cañon (Univ. Mich. Mus.); 3 miles south of Halleck (U. S. N. M.); west side of Ruby Lake (Mus. Vert. Zool.); Elko (Calif. Acad. Sci.); Carlin (Calif. Acad. Sci.).

Churchill County: Near Fallon (U. S. N. M.).

White Pine County: Cleveland Ranch, Spring Valley (Mus. Vert. Zool.); Steptoe Creek, 6,100 feet, 5½ miles southeast of Ely (Mus. Vert. Zool.).

Lincoln County: 3½ miles north of Eagle Valley, 5,600 feet (Mus. Vert. Zool.); Crystal Spring, 2 miles south, and 3 miles north (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); 4

miles south of Alamo (Mus. Vert. Zool.); Caliente (Calif. Acad. Sci.).

Clark County: Colorado River, opposite Fort Mojave (Mus. Vert. Zool.).

The leopard frog was reported as common in the upper Humboldt Valley by Ruthven and Gaige (1915, p. 12). Adults were found in the water of stagnant pools or on their banks, and only occasionally in running water. They were shy and hard to capture. Stomachs contained small toads, a few tadpoles, and insects. Specimens taken on July 18, contained eggs. The ground color in life was almost invariably dark gray, only one green one was obtained; small and recently transformed ones were grayish brown with small, round, dark brown spots.

On May 18, 1932, at Crystal Spring, Lincoln County, Fitch (MS) recorded in his notes that fourteen mouse traps put out the night before along the creek from Crystal Spring to a point 100 yards east, all in thick rushes on damp ground and within a few inches of the water, held two leopard frogs and two harvest mice (*Reithrodontomys*) in the morning.

Rana pretiosa luteiventris Thompson

Spotted Frog

Original description.—*Rana pretiosa luteiventris* Thompson, Proc. Biol. Soc. Wash., vol. 26, 1913, p. 53 (Annie Creek, Elko County, Nevada).

Synonym for Nevada.—*Rana pretiosa*, Slevin, 1928, p. 136.

Range.—Southeastern Washington, Idaho, eastern Oregon, northeastern California, and northern Nevada.

Occurrence in Nevada.—All localities so far reported for this frog are in southwestern Elko County, in the upper part of the Humboldt Valley, and in northern Humboldt County. In altitude they are close to 5,000 feet.

Additional specimens (Univ. Mich.) collected in 1938 by C. L. Hubbs from the Reese River Valley in Lander and Nye counties extend the known range of this frog more than 100 miles southward.

The specimen from Lake Tahoe, reported as this species (Slevin, 1928, p. 136), was examined by me on November 7, 1933, in the U. S. N. M. It proved to be *R. b. sierrae*.

Nevada localities (1 specimen in Museum of Vertebrate Zoology).—

Humboldt County: Quinn River, near McDermitt (Stan. Univ.).

Elko County: Annie Creek (Univ. Mich.); Maggie Creek (Univ. Mich.); Humboldt River Valley (Univ. Mich.).

Eureka County: Pine Creek, 2 miles east of Palisade (Mus. Vert. Zool.).

These frogs were found by Ruthven and Gaige (1915, p. 13) along the edges of flowing streams or with their heads projecting above the vegetation of ponds. They were very shy and disappeared quickly when disturbed, but usually reappeared within a short time in about the same place.

REPTILIA

Subclass Diapsida

Order **Squamata**

Suborder Sauria

GEKKONIDAE

Coleonyx variegatus (Baird)

Banded Gecko

Original description.—*Stenodactylus variegatus* Baird, Proc. Acad. Nat. Sci. Phila., vol. 12, 1858 (1859), p. 254 (Rio Grande and Gila valleys = Colorado Desert, in southern California).

Range.—Southern California and northern Lower California east to southwestern Utah and Texas.

Occurrence in Nevada.—Several specimens represent localities south from 37° N. to the Colorado River. Altitudinally, the species has been captured up to 4,000 feet. The animals are active at night and are sometimes found in the daytime beneath rocks or other shelter on the ground.

Nevada localities (Fig. 6) (9 specimens in Museum of Vertebrate Zoology).—

Nye County: Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.).

Clark County: Mouth of Kyle Cañon, 4,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 37); Glendale (Klauber, 1932, p. 120); Jean (Mus. Vert. Zool.); Colorado River, 20 miles above Boulder Dam (Mus. Vert. Zool.); near mouth of Virgin River (Mus. Vert. Zool.); Colorado River near Boulder Dam (Cowles and Bogert, 1936, p. 37); Colorado River, 5 miles north of California boundary (Mus. Vert. Zool.).

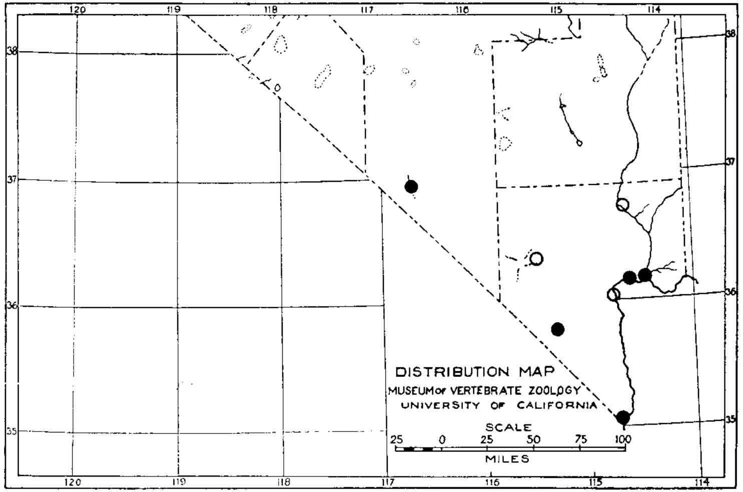
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FIG. 6. Distribution of *Coleonyx variegatus* in southern Nevada.

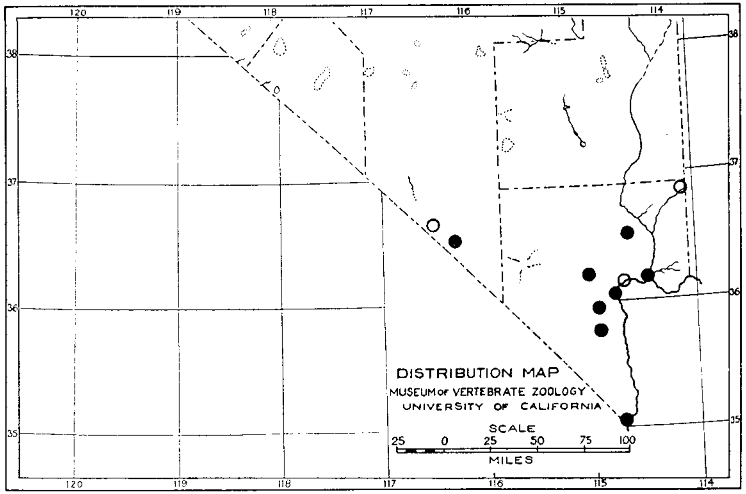
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FIG. 7. Distribution of *Dipso-saurus dorsalis dorsalis* in southern Nevada.

IGUANIDAE

Dipso-saurus dorsalis dorsalis

(Baird and Girard)

Desert Iguana

Original description.—*Crotaphytus dorsalis* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 126 (Colorado Desert, California).

Synonym for Nevada.—*Dipsosaurus dorsalis*, Van Denburgh, 1897, p. 46.

Range.—Desert areas of southeastern California, southern Nevada and adjacent parts of Utah, Arizona and south to central Lower California.

Occurrence in Nevada.—Specimens have been captured on the Amargosa Desert and in the near vicinity of the Virgin and Colorado rivers.

Nevada localities (Fig. 7) (31 specimens in Museum of Vertebrate Zoology).—

Nye County: Amargosa Desert (U. S. N. M.); 3 miles northeast of Fairbanks Spring (Mus. Vert. Zool.).

Clark County: Mesquite (Woodbury, 1931, p. 22); Callville (U. S. N. M.); near mouth of Virgin River (Mus. Vert. Zool.); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.); 10 miles northeast of Las Vegas, 2,000 feet (Mus. Vert. Zool.); Colorado River, 3 and 12 miles above Boulder Dam (Mus. Vert. Zool.); vicinity of Boulder City (Cowles and Bogert, 1936, p. 37); 25 miles south of Las Vegas, on Searchlight road (Mus. Vert. Zool.); Hiko Spring, 2,000 feet, Dead Mountains (Mus. Vert. Zool.); 2 miles northwest of Fort Mojave, 500 feet (Mus. Vert. Zool.); Colorado River, 5 miles north of California boundary (Mus. Vert. Zool.); 22 miles north of Searchlight (Mus. Vert. Zool.).

Most of the thirty-one specimens (in Mus. Vert. Zool.) from Nevada show distinct longitudinal dark lines on the sides of the body. Nine have two full rows of granules, on both sides, between rostral and nasal scales; 13 have at least one granule on each side touching both rostral and nasal; eight have a complete double row of granules on one side and at least one single granule on the other; one has a single granule on one side and the other damaged.

Crotaphytus collaris baileyi Stejneger

Collared Lizard

Original description.—*Crotaphytus baileyi* Stejneger, N. Amer. Fauna, 3, 1890, pp. 103–105, pl. 12, fig. 1 (Painted Desert, Little Colorado River, Arizona).

Synonyms for Nevada.—*Crotophytus collaris*, Yarrow, 1883, p. 52.

Crotaphytus collaris baileyi, Stone, 1911, p. 224.

Crotaphytus baileyi, Van Denburgh, 1897, p. 56.

Range.—Eastern Oregon and southern Idaho east through Utah and Colorado to western New Mexico and southwestern Texas, and south to Lower California and northern Mexico. Another race, closely related, occupies the territory south of the 40th parallel east to the Mississippi River.

Occurrence in Nevada.—Collared lizards live throughout the state, but they are restricted locally to a rather specialized habitat. Rocks make up the most conspicuous indicator of this suitable habitat; they are used in several ways by the lizards. They tend to be present in large numbers around the bases of mountain ranges. Fewness of records in the southern part of the state seems to indicate considerably reduced numbers there compared with the higher deserts. Most of the localities are between altitudes of 4,000 and 6,500 feet, but they extend from 1,000 to 7,500 feet.

Nevada localities (Fig. 8) (105 specimens in Museum of Vertebrate Zoology).—

Washoe County: Truckee River, between Reno and Pyramid Lake (U. S. N. M.); Derby (U. S. N. M.); Smoke Creek (U. S. N. M.); Smoke Creek Desert (U. S. N. M.); 1 mile northeast of Gerlach, 4,000 feet (Mus. Vert. Zool.); 1 mile west of Derby (Univ. Mich.); Pyramid Lake Indian Agency (U. S. N. M.); 7 miles east of Vista (U. S. N. M.); 6 miles south of Pahrum Peak (Mus. Vert. Zool.).

Lyon County: Mason, 4,500 feet (Van Denburgh, 1922, p. 108); Dayton (Calif. Acad. Sci.); 29 and 23 miles west of Fallon, 4,300 feet (Mus. Vert. Zool.).

Humboldt County: Thousand Creek Basin (Mus. Vert. Zool.); Limestones (Mus. Vert. Zool.); Big Creek Ranch (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.).

Pershing County: South slope Granite Peak, East Range (Mus. Vert. Zool.); 12 miles west and 2 miles south of Lovelock, 5,100 feet (Mus. Vert. Zool.).

Churchill County: near Fallon (U. S. N. M.); mountains east of Stillwater (U. S. N. M.); 3 miles west and 7 miles east of Frenchman's

Station (U. S. N. M.); no locality given (Burt, 1928, p. 15).

Eureka County: Cortez Mountains at Humboldt River (Univ. Mich.).

White Pine County: Mt. Moriah near Smith Creek Cave (Mus. Vert. Zool.).

Mineral County: Endowment Mine (Mus. Vert. Zool.).

Esmeralda County: Palmetto Mountains (Richardson, 1915, p. 406).

Nye County: Ridge north of Wisconsin Creek, 7,500 feet (Mus. Vert. Zool.); North Twin River, 6,500 feet (Mus. Vert. Zool.); South Twin River, 6,500 feet (Mus. Vert. Zool.); Wall Cañon, 6,500 feet (U. S. N. M.); north Kingston Mountains (Van Denburgh, 1922, p. 108); Tonopah (Calif. Acad. Sci.); Rhyolite (Calif. Acad. Sci.); Oasis Valley (U. S. N. M.); Currant (Bentley, 1919, p. 88); 1½ miles southwest of Cactus Spring, Cactus Range (Mus. Vert. Zool.); 2 miles northwest of Indian Spring, Belted Range (Mus. Vert. Zool.); 6, 8, and 9 miles east of Cliff Spring (Mus. Vert. Zool.); White River Valley, 14 miles west-southwest of Sunnyside (Mus. Vert. Zool.); Hot Creek Range, 6,700 feet, 8 miles west of Tybo (Mus. Vert. Zool.).

Lincoln County: vicinity of Crystal Spring (Mus. Vert. Zool.); Ash Spring (Mus. Vert. Zool.); 22 miles east of Panaca (U. S. N. M.); Caliente (Calif. Acad. Sci.); Quartz Spring in Desert Mountains (U. S. N. M.); Juniper Mountains (Van Denburgh, 1922, p. 108).

Clark County: vicinity of Boulder City (Cowles and Bogert, 1936, p. 37); 19 miles south of Las Vegas, 2,000 feet (Mus. Vert. Zool.); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.).

Out of the 99 specimens in the Museum of Vertebrate Zoology, 96 have two distinct rows of interorbital scales. Three have one pair of these scales fused into a single scale.

In the Lahontan Basin, Richardson (1915, p. 407) found collared lizards only on hillsides among deposits of tufa and outcroppings of volcanic rock at an elevation of 4,500 feet. Ruthven and Gaige (1915, p. 17) in Eureka County, Nevada, found the species in only one place—the rocky summits of the Cortez Mountains. They found not more than six in four or five hours work, and many days they found none. One or two were on the ground, the rest on rocks. Because this lizard was usually on the tops of rocks or clinging to slopes and not on cliffs, it was concluded that it was a poorer climber than *Sceloporus occidentalis* or *Uta stansburiana*. When alarmed they rushed down into crevices. Stomachs contained insects and spiders.

In the neighborhood of Crystal Spring, Pahranagat Valley, Fitch (MS) on May 20, 1932, collected several and saw others in small rocky ravines and along the sides of ridges. They sometimes escaped down a hole, but usually ran beneath the nearest rock. If the rock were turned over, the lizards seemed greatly confused, running off into the bushes and then returning several times to the spot where the rock had been before finally concealing themselves under another rock. On June 1, at 5,900 feet, north of Cliff Spring in Nye County, the same observer found this species in boulder strewn areas in foothills, where there was also gravel. It was found down in the sagebrush area where rocky ravines extended down into it. One young individual was shot after it had run under the edge of a sage bush. All others, when alarmed, hid under boulders. In the White River Valley, Nye County, on June 8, Fitch found one which was clinging to a boulder, just before sunset and which allowed him to approach and capture it by hand before showing sign of alarm. Another, found shortly after sunset the same day, was in a refuge place beneath a boulder.

Crotaphytus wislizenii Baird and Girard

Leopard Lizard

Original description.—*Crotaphytus Wislizenii* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 69 (Near Santa Fé, New Mexico).

Synonym for Nevada.—*Crotaphytus wislizeni*, Yarrow, 1883, p. 53.

Range.—Western United States from southern Oregon and Idaho south through Lower California and to northwestern Sonora; from eastern California to Texas.

Occurrence in Nevada.—Widespread in the valleys and flats throughout the state, but especially common on the plateau at altitudes between 4,000 and 6,000 feet.

Nevada localities (Fig. 9) (221 specimens in Museum of Vertebrate Zoology).—

Washoe County: Near Reno (Calif. Acad. Sci.); Smoke Creek Desert (U. S. N. M.); Smoke Creek, 3,900 feet (Mus. Vert. Zool.); 1 mile south of Warm Spring (Mus. Vert. Zool.); Flanigan, 4,200 feet (Mus. Vert. Zool.); 4½ miles south of Flanigan, 4,100 feet (Mus. Vert.

Zool.); 2 miles northeast of Sand Pass (Mus. Vert. Zool.); Fox Cañon, south of Pahrum Peak (Mus. Vert. Zool.); north end of Pyramid Lake (Mus. Vert. Zool.); 1 mile northwest of The Needles (Mus. Vert. Zool.); near Sutcliffe (Calif. Acad. Sci.); Pyramid Lake Indian Agency (U. S. N. M.); Truckee River 12 and 1 miles northwest of Wadsworth (Mus. Vert. Zool.); Wadsworth (U. S. N. M.).

Ormsby County: Carson City (U. S. N. M.).

Lyon County: Mason Valley, 12 miles east of Wellington (Mus. Vert. Zool.); 12 miles south of Yerington (Mus. Vert. Zool.); 22 miles west of Fallon (Mus. Vert. Zool.); 6½ miles east of Dayton (Mus. Vert. Zool.).

Humboldt County: Big Creek Ranch (Mus. Vert. Zool.); Alder Creek (Mus. Vert. Zool.); Leonard Creek (Mus. Vert. Zool.); Thousand Creek Flat (Mus. Vert. Zool.); Limestones (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); Amos (Mus. Vert. Zool.); Winnemucca (Univ. Mich. Mus.); 23 miles northwest of *Battle Mountain (Mus. Vert. Zool.); 7 miles* north of Winnemucca (Mus. Vert. Zool.); Golconda (U. S. N. M.); 1 mile south of Golconda (Mus. Vert. Zool.).

Elko County: Annie Creek (Univ Mich.); Carlin (Calif. Acad. Sci.).

Pershing County: Rabbit Hole, Mount Playa (U. S. N. M.); 3 miles south of Vernon, 4,200 feet (Mus. Vert. Zool.); 2 miles west of Toulon (Mus. Vert. Zool.); 30 miles west and 4 miles north of Lovelock, 4,300 feet (Mus. Vert. Zool.); 21 miles west and 2 miles north of Lovelock, 4,000 feet (Mus. Vert. Zool.); west base Granite Peak, East Range (Mus. Vert. Zool.).

Churchill County: Mountain Well (Mus. Vert. Zool.); Hazen (U. S. N. M.); 7 miles west of Frenchman's Station (Univ. Mich.); 2 miles east of Sand Springs (U. S. N. M.).

Lander County: 15 miles north of Battle Mountain (Mus. Vert. Zool.); Battle Mountain (U. S. N. M.); 26 miles north of Austin (Mus. Vert. Zool.); Smoky Valley, between Birch and Kingston creeks (Mus. Vert. Zool.); Kingston Creek, 6,200 feet (Mus. Vert. Zool.); 8 and 10 miles northeast of Tenabo (Mus. Vert. Zool.).

Eureka County: Beowawe (U. S. N. M.); 14 and 18 miles northeast of Tenabo (Mus. Vert. Zool.).

White Pine County: Baker (Mus. Vert. Zool.); Antelope Springs (Van Denburgh, 1922, p. 123); Snake Creek (Van Denburgh, 1922, p. 123).

Mineral County: 6 miles northeast of Pine Grove (Mus. Vert. Zool.); 3 and 8 miles south of Schurz (Mus. Vert. Zool.); Huntoon Valley, 6,700 feet (Mus. Vert. Zool.); Hawthorne (Van Denburgh, 1922, p. 122).

Esmeralda County: 15 miles south of Tonopah (Mus. Vert. Zool.); Gap Spring (Mus. Vert. Zool.); 7 miles north and 7 miles east of Arlemont (Mus. Vert. Zool.); Arlemont (Mus. Vert. Zool.); Chiatovich Creek, 7,000 feet (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.); Mount Magruder (U. S. N. M.); 13½ miles northwest of Goldfield (Mus. Vert. Zool.); Goldfield (Calif. Acad. Sci.); Grapevine Mountains (U. S. N. M.).

Nye County: Wisconsin Creek, 6,000 feet (Mus. Vert. Zool.); South Twin River, 6,000 feet (Mus. Vert. Zool.); Peavine Creek, 6,200 feet (U. S. N. M.); vicinity of Millett P. O., Smoky Valley (Mus. Vert. Zool.); Cloverdale Ranch (Mus. Vert. Zool.); Round Mountain (U. S. N. M.); Tonopah (Calif. Acad. Sci.); 8 to 14 miles *southeast of Tonopah (Mus. Vert. Zool.);* Currant (Bentley, 1919, p. 89); Rhyolite (Calif. Acad. Sci.); Oasis Valley (U. S. N. M.); Amargosa Desert (U. S. N. M.); 22 miles southeast of Beatty (Mus. Vert. Zool.); Pahrump Valley (U. S. N. M.); 7½ miles east of Cliff Spring, 5,900 feet (Mus. Vert. Zool.); Garden Valley (Mus. Vert. Zool.); White River Valley, 15 miles southwest of Sunnyside (Mus. Vert. Zool.); Hot Creek Valley, 5½ and 6½ miles east of Hot Creek (Mus. Vert. Zool.); Amargosa Desert (U. S. N. M.).

Lincoln County: 9 and 16 miles east of Groom Baldy (Mus. Vert. Zool.); Penoyer Valley, 14 miles north-northwest of Groom Baldy (Mus. Vert. Zool.); ¼ mile south of Hiko (Mus. Vert. Zool.); Crystal Spring (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); Caliente (U. S. N. M.); Panaca (U. S. N. M.); Quartz Spring (U. S. N. M.); Timpahute Mountains (U. S. N. M.).

Clark County: Cottonwood Spring, Charleston Mountains (U. S. N. M.); Indian Spring Valley (U. S. N. M.); Vegas Valley (U. S. N. M.); 3 miles south of Mesquite, 2,500 feet (Mus. Vert. Zool.); Saint Thomas (U. S. N. M.); Piute Valley, 10 miles south of Searchlight and 1 mile north of California line (Klauber, 1932, p. 121); 14 miles northeast of Searchlight, 3,500 feet (Mus. Vert. Zool.); Boulder City (Klauber, 1932, p. 121; Cowles and Bogert, 1936, p. 37); 5 miles west of Hiko Spring (Mus. Vert. Zool.);

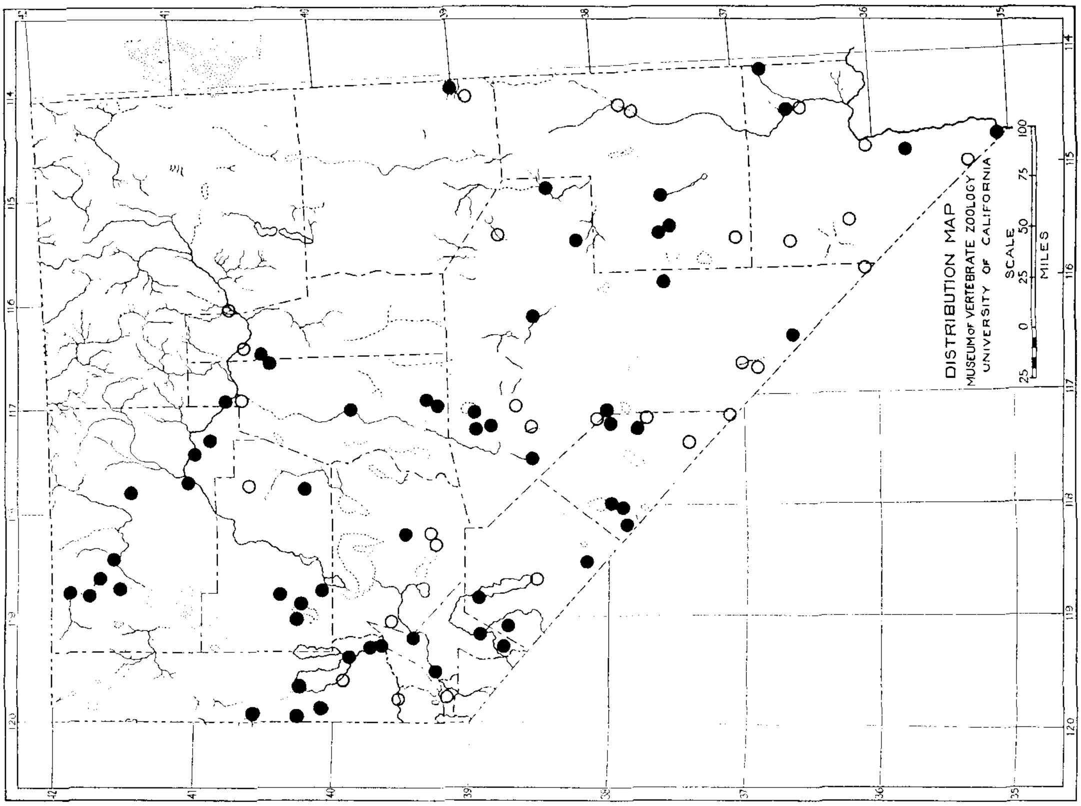
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FIG. 9. Distribution of *Crotaphytus wislizenii* in Nevada.

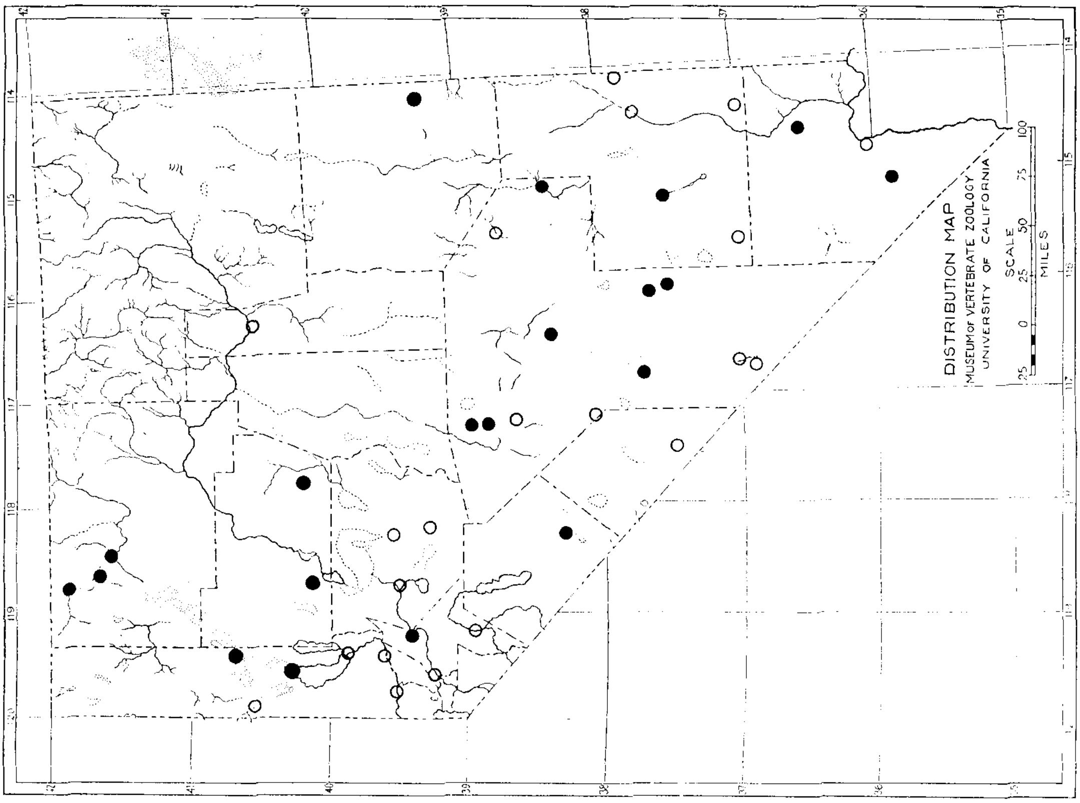
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FIG. 8. Distribution of *Crotaphytus collaris baileyi* in Nevada.

Hiko Spring, 2,000 feet (Mus. Vert. Zool.); 5 miles southeast of Overton (Mus. Vert. Zool.).

In the Lahontan Basin, Richardson (1915, p. 408) found leopard lizards on the desert among low growths of sagebrush and other shrubs. Breeding activities were indicated as follows. Two females from Pyramid Lake Indian Agency, between May 26 and June 1, contained two and four eggs. One at Derby, June 29, had two eggs, and one at Carson City, July 10, had three. The last one had brilliant red-orange breeding colors. A female taken in Elko County on July 13 contained eggs and the first young one (129 mm. long) was found in this vicinity on August 14.

Merriam (in Stejneger, 1893, p. 168) has given a full account of special coloration of this species in the breeding season, as follows: "In many lizards, as well known, the male assumes a special coloration during the breeding season. The present species is a notable exception, the male remaining the same, while the female undergoes a remarkable change. The whole under surface and sides of the tail become deep salmon or even salmon red, and the sides of the body assume the same color, either uniformly or in blotches. The red markings on the sides usually begin as spots, which soon unite to form transverse stripes. The central part of the back is not affected by the change, and the dark markings on the sides remain distinct. None were seen in this condition until May 20, when the first red one was found on Pahroc Plain, Nev., but dozens were seen afterward in Pahranagat Valley, Indian Spring Valley, the Amargosa Desert, Tule Cañon, and numerous other localities. The change does not take place till late in the development of the egg. Many pairs were observed in copulation in Diamond and the Upper Santa Clara Valleys, Utah, and thence northward to Mountain Meadows and the Escalante Desert, and westerly across the Juniper Mountains to Meadow Creek Valley from May 11 to 19, but no trace of the red coloration had appeared. The red individuals were always found to contain large eggs, generally measuring from 12 to 15 mm. in length, with the coriaceous shell already formed."

The leopard lizard in Nevada feeds mainly upon large insects, such as grasshoppers, and other lizards. The following kinds of lizards have been identified as items of food in this area: *Crotaphytus wislizenii*, *Uta stansburiana*, *Sceloporus graciosus*, *Sceloporus magister*, *Cnemidophorus tesselatus*, *Phrynosoma platyrhinos*.

Fitch (MS) made observations in 1932, in southern Nevada, on this species as follows. On May 14, at 10:30 a. m., he found a mating pair in a road 14 miles southeast of Tonopah. Tracks in the dust showed where the female had dragged the male. They permitted persons to approach within a few feet without separating. Near Crystal Spring, Lincoln County, on May 19, another mating pair was found at 6 p. m. That morning at 5:30 o'clock, a leopard lizard was found sunning itself on a rock. The animal was dark in color and so sluggish that it was approached and caught by hand before it moved.

The leopard lizard proved to be one of the commonest reptiles of the desert in Humboldt County (Taylor, 1912, p. 347). It was found in washes and on lesser ridges of the open desert, under various species of desert plants and was much more common along the eastern foothills of the mountains than at any other locality visited. When really surprised the lizards exhibited great speed, never stopping until they reached some convenient bush, into the shelter of which they crawled and remained quiet. One escaped by running into a burrow. One was shot in the top of a low thorny bush. When handled certain individuals made a hissing sound and vigorously attempted to bite; one uttered a low moaning sound. While at rest they kept the head raised from the ground and watched an intruder, but when in motion they lowered it. One ran into a bush after a cicada which apparently it failed to secure. Next it crawled along slowly, occasionally protruding its tongue. When a fly buzzed about the bush and lit nearby the lizard crawled slowly toward it, and as the insect left the ground the lizard jumped four inches into the air after it. In the jump all four feet left the ground. The first female showing the red coloration of the breeding season was captured on June 8.

On June 7, 1932, in Garden Valley, Nye County, a leopard lizard was shot after it ran from a clump of grass late in the afternoon. It was muddy and dark colored, relatively sluggish, apparently having just come out after two days of cold and rainy weather.

Sauromalus obesus (Baird)

Chuckwalla

Original description.—*Euphryne obesus* Baird, Proc. Acad. Nat. Sci., vol. 12, 1858 [1859], p. 253 (Fort Yuma, Arizona).

Synonym for Nevada.—*Sauromalus ater*, Van Denburgh and Slevin (1921, p. 30).

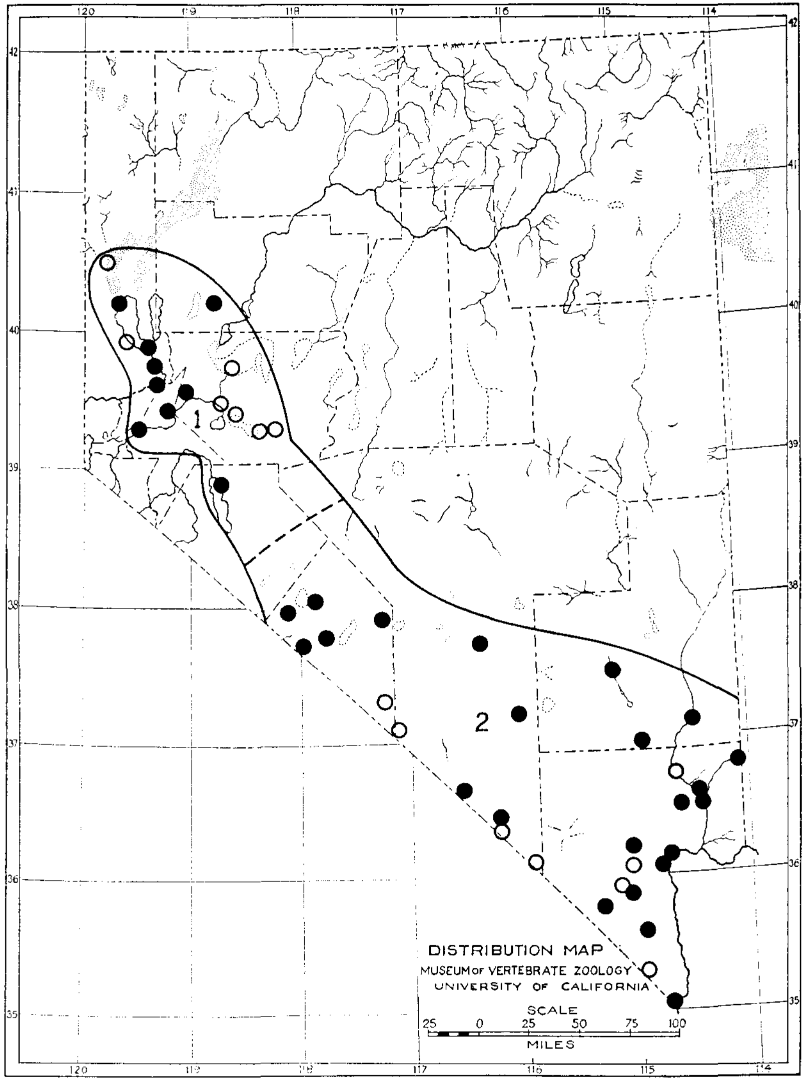
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FIG. 11. Distribution of *Callisaurus draconoides* in Nevada (1, *C. d. myurus*; 2, *C. d. gabbii*).

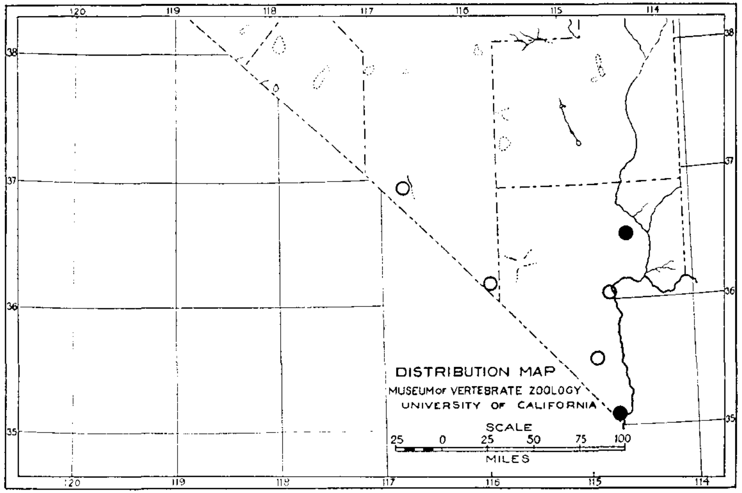
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FIG. 10. Distribution of *Sauromalus obesus* in southern Nevada.

Range.—Southern Nevada, southwestern Utah, Arizona, southern California, and northern Lower California.

Occurrence in Nevada.—The chuckwalla has been captured at several localities in the southern part of the state, north to Rhyolite. They are all south of 37° N. and below 4,000 feet altitude. Rocky sections of the desert provide suitable habitat.

Nevada localities (Fig. 10) (6 specimens in Museum of Vertebrate Zoology).—

Nye County: Rhyolite (Calif. Acad. Sci.); Pahrump Valley (U. S. N. M.).

Clark County: Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.); Searchlight (Klauber, 1932, p. 121); Hiko Spring (Mus. Vert. Zool.); 9½ miles south of Dead Mountain, 2,200 feet (Mus. Vert. Zool.); vicinity of Boulder Dam (Cowles and Bogert, 1936, p. 37).

Callisaurus draconoides gabbii Cope

Gridiron-tailed Lizard

Original description.—*Callisaurus draconoides gabbii* Cope, Rept. U. S. Nat. Mus., 1898 [1900], p. 272 (northern Lower California).

Synonyms for Nevada.—*Callisaurus ventralis* (part), Van Denburgh, 1897, p. 50.

Callisaurus draconoides ventralis, Cope, 1900, p. 274.

Callisaurus ventralis ventralis, Van Denburgh and Slevin, 1921, p. 31.

Range.—Southern Nevada, western Arizona, southeastern California, and northern Lower California.

Occurrence in Nevada.—This race is one of the most abundant lizards on the sandy and gravelly ground in southern Nevada, north to about the 38th parallel. Records show its presence nearly across Esmeralda County and north to central Nye and Lincoln counties. It is found usually on the floors of the valleys and is especially abundant on areas of pure sand. A long period of collecting in northern Nye County and other localities failed to show the presence of this lizard on the high plateau of central and northern Nevada.

Nevada localities (Fig. 11) (311 specimens in Museum of Vertebrate Zoology).—

Esmeralda County: 7 miles north of Arlemont (Mus. Vert. Zool.); Big Smoky Valley (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.); 2 miles northwest of Cave Spring, 5,700 feet (Mus. Vert. Zool.); Gold Mountain (Stejneger, 1893, p. 172); 15 miles south of Tonapah (Mus. Vert. Zool.).

Nye County: Amargosa Desert, 20 miles southeast of Beatty (Mus. Vert. Zool.); Amargosa Desert, Thorps Mill (U. S. N. M.); 3 miles northeast and 2 miles southeast of Fairbanks Spring (Mus. Vert. Zool.); Ash Meadows (U. S. N. M.); Pahrump Valley (U. S. N. M.); 4½ miles southeast of Oak Springs, 4,750 feet (Mus. Vert. Zool.); south end of Kawich Range (Mus. Vert. Zool.).

Lincoln County: Crystal Spring (Mus. Vert. Zool.); 11 miles south of Hiko (Mus. Vert. Zool.); Ash Spring, 3,800 feet (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); 6 miles northeast of Carp, 3,000 feet (Mus. Vert. Zool.); 1 mile west of Coyote Spring, 2,500 feet (Mus. Vert. Zool.).

Clark County: 2 and 5 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); 8 miles south of Saint Thomas (Mus. Vert. Zool.); Glendale (Klauber, 1932, p. 121); Sloan (*ibid.*); Boulder City (*ibid.*); Las Vegas Wash, 11 and 16 miles southeast of Las Vegas (*ibid.*); Piute Valley, 10 miles south of Searchlight and 1 mile north of California line (*ibid.*); 10 miles northeast of Las Vegas (Mus. Vert. Zool.); Colorado River, 3 and 12 miles above Boulder Dam (Mus. Vert. Zool.); Callville (U. S. N. M.); 19 miles south of Las Vegas (Mus. Vert. Zool.); opposite Fort Mojave (Mus. Vert. Zool.); 1 mile west of Jean (Mus. Vert. Zool.); Hiko Spring, 2,000 feet (Mus. Vert. Zool.); 5 and 12 to 20 miles north of Searchlight, 3,500 feet (Mus. Vert. Zool.); Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); 3 miles south of Mesquite, 2,500 feet (Mus. Vert. Zool.); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.).

The race *gabbii* was characterized and compared with *draconoides* in the original description by Cope (1900, p. 272) as follows: "A band of granular scales behind collar only. Superciliary scales equal frontals and in contact on middle line; larger scales before ear; legs longer; wrist beyond muzzle, hind foot mostly so."

Callisaurus draconoides gabbii exhibits characters as follows: Males have two large oblique lateral black blotches usually not followed by a third black spot; dark dorsal tail bars with nearly straight or slightly undulate posterior margins at least from middle to end of tail; dorsal tail bars black in males; occipital and supraorbital semicircles usually separated by a row of scales (reverse of condition in *C. d. ventralis*); ratio of tail length to total length greater than in *C. d. ventralis;* ratio of length of hind leg to body length greater than in *C. d. ventralis;* femoral pores average less than 17 (17 or more is average in *C. d. ventralis*).

Merriam (in Stejneger, 1893, p. 171) gave an extended account of the habits of this lizard in southern Nevada where he considered it the most characteristic reptile of the deserts. He found it almost universally distributed there and much more abundant than any other species. He wrote that "it starts off at full speed, as if fired from a cannon, and stops with equal suddenness, thus escaping or eluding its enemies, the coyotes, hawks, and larger lizards. When running it moves so swiftly that the eye has difficulty in following, and when at rest its colors harmonize so well with those of the desert that it can hardly be seen.

"The attitude of this lizard when at rest differs from that of most others in that the knees and elbows stand out at right angles from the body and are elevated to such a degree that they nearly reach the plane of the back. Like many other species, it has an odd habit of performing a singular gymnastic exercise, consisting in rapidly dropping and elevating the body with the knees held stiff at right angles to the trunk."

The same observer found the food of this lizard to be insects and the blossoms and leaves of plants. He noted that during the breeding season the males develop a conspicuous patch of metallic greenish-blue on the sides of the body and have the power of inflating a pinkish sac under the chin.

Geographic variation in Nevada was observed by Merriam (*op. cit.*, p. 172), as follows. "In Desert Valley, just east of the Pahroc Mountains, a form of this species was found which seems to be subspecifically distinct from the ordinary type. It is much shorter and broader, with a shorter tail, and is bluish-gray in color. It may be the same as the animal inhabiting the desert at Pyramid Lake, Nevada, which point is about two degrees further north than Desert Valley, though in the same zoological sub-zone, for the low altitude of a series of narrow and irregular deserts in western Nevada carries this zone much farther north than elsewhere. These specimens suggest the existence of a form peculiar to the upper division (or *Grayia* belt) of the Lower Sonoran Zone, *Callisaurus ventralis* [= *gabbii*] proper being closely restricted to the lower division (or *Larrea* belt) of the same zone."

Callisaurus draconoides myurus Richardson

Gridiron-tailed Lizard

Original description.—*Callisaurus ventralis myurus* Richardson, Proc. U. S. Nat. Mus., vol. 48, 1915, p. 408 (Pyramid Lake Indian Agency, Washoe County, Nevada).

Synonyms for Nevada.—*Callisaurus ventralis* (part), Van Denburgh, 1897, p. 50.
Callisaurus draconoides ventralis, Burt, 1933, p. 230.

Range.—Western Nevada.

Occurrence in Nevada.—This race is most abundant in the vicinity of Pyramid Lake, but it has been found at other localities in southern Washoe County, Lyon County, western Pershing and Churchill counties, and northern Mineral County. Its range may not be so sharply cut off from the rest of the species as the records shown on the map indicate. However, some collecting has been done in the intervening area.

Nevada localities (Fig. 11) (87 specimens in Museum of Vertebrate Zoology).—

Washoe County: North end Pyramid Lake (Mus. Vert. Zool.); The Needles (Mus. Vert. Zool.); The Willows (U. S. N. M.); near Sutcliffe (Calif. Acad. Sci.); Pyramid Lake Indian Agency (Mus. Vert. Zool.; U. S. N. M.); Truckee River, 12 miles northwest of Wadsworth (Mus. Vert. Zool.); Big Bend of Truckee River (U. S. N. M.); Wadsworth (Mus. Vert. Zool.; U. S. N. M.); Derby (U. S. N. M.); Smoke Creek Desert (U. S. N. M.).

Lyon County: 27, 23, 20, and 18 miles west of Fallon, 4,300 feet (Mus. Vert. Zool.); 6½ miles east of Dayton (Mus. Vert. Zool).

Pershing County: 16 miles west of Lovelock (Mus. Vert. Zool.).

Churchill County: 3 miles west of Hazen (Mus. Vert. Zool.); Fallon (U. S. N. M.); Carson Sink (U. S. N. M.); near Sand Springs (Univ. Mich.; U. S. N. M.); 1 mile southeast of Salt Wells and 3 miles west of Frenchman's Station (Burt, 1933, p. 232).

Mineral County: 6 and 8 miles south of Schurz (Mus. Vert. Zool.).

Callisaurus d. myurus, the northernmost race in the species, reaches an extreme in several directions of development. It has a shorter tail, fewer femoral pores, and darker dorsal coloration compared with races immediately to the south.

All Nevada specimens of this species were measured, but the summary shown in the accompanying tabulation applies to only eighty or about one fifth of the individuals. Twenty of the largest ones were selected and measured from each of four localities.

Locality		Body-length	Tail-length	Ratio of Body-length to Tail-length	Length of Hind leg	Femoral pores
Virgin River near Overton	Av.	77.3	105.1	.73	73.2	16.14
	Min.	73.0	99.8		69.0	14
	Max.	84.1	116.2		79.1	19
Colorado River near Fort Mojave	Av.	77.6	103.0	.75	73.8	16.56
	Min.	69.9	94.0		65.5	14
	Max.	87.5	118.5		81.0	20
Amargosa Desert	Av.	75.75	98.8	.77 –	73.2	16.09
	Min.	68.2	81.2		65.5	13
	Max.	81.6	116.5		79.5	19
Pyramid Lake	Av.	76.7	94.9	.80	70.8	13.59
	Min.	74.5	87.5		63.4	11
	Max.	81.0	103.9		78.2	16

In the region of Pyramid Lake this is the most abundant reptile over most of the area. Richardson (1915, p. 411) observed that it occurred in greatest numbers on the sandy desert among low shrubs. He saw none in dense growths of sagebrush or on rocky hillsides. He noted that it was swift, often running a hundred feet or more when disturbed, and that it seldom ran straight ahead of an intruder, but usually moved off to the right or left in an arc. When in rapid motion, the tail was raised above the level of the body, but never curled over the back. The tail was curled over the back sometimes when a lizard was moving slowly. During a light thundershower many of the lizards were found buried in loose desert sand, where they remained until nearly stepped on before moving. A wounded individual uttered a high-pitched cry when handled. Seven stomachs contained wasps, grasshoppers, spiders, larvae of insects, and vegetable material. Three females taken on May 31 at the south end of Pyramid Lake contained 4, 5, and 6 large eggs each.

As Richardson (1915, p. 411) has already pointed out the *Holbrookia* reported from "north of Pyramid Lake" by Cope (1883, p. 18) was no doubt this form.

Uta graciosa (Hallowell)

Long-tailed Uta

Original description.—*Uro-saurus graciosus* Hallowell, Proc. Acad. Nat. Sci. Phila., vol. 7, 1854, pp. 92–93 ("Lower California" [= southern California]).

Range.—Southern California, southern Nevada, southwestern Arizona, and northeastern Lower California.

Occurrence in Nevada.—All records are from localities in southern and eastern Clark County, mostly in the vicinity of the Virgin and Colorado rivers. Cowles and Bogert (1936, p. 37) found this lizard especially common in the creosote bushes bordering a stream near Boulder City.

Nevada localities (Fig. 13) (21 specimens in Museum of Vertebrate Zoology).—

Clark County: Bunkerville (U. S. N. M.); Mesquite (San Diego Soc. Nat. Hist.); 2 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); Kaolin, 1,220 feet (Mus. Vert. Zool.); Callville (U. S. N. M.); Colorado River, 25 miles above Boulder Dam (Mus. Vert. Zool.); Boulder City (Cowles and Bogert, 1936, p. 37); 10 miles northeast of Las Vegas, 2,000 feet (Mus. Vert. Zool.); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.).

Uta ornata symmetrica Baird

Tree Uta

Original description.—*Uta symmetrica* Baird, Proc. Acad. Nat. Sci. Phila., 1858, p. 253 (Fort Yuma, Arizona).

Synonym for Nevada.—*Uta ornata ornata*, Stejneger and Barbour, 1933, p. 57.

Range.—Valley of the Colorado River and the adjacent Colorado Desert.

Occurrence in Nevada.—Definite localities are all along the Colorado River on the southern border of the state. Cowles and Bogert (1936, p. 38) report this species as confined almost entirely to the steepest cañon walls. Yarrow (1883, p. 56) reported a specimen (no. 8641, U. S. N. M.) collected by himself in 1872, in Nevada, but no definite locality specified. Van Denburgh and Slevin (1921, p. 28) queried this species in their list of amphibians and reptiles of Nevada.

Nevada localities (No specimens in Museum of Vertebrate Zoology).—

Clark County: Black Cañon (Cowles and Bogert, 1936, p. 38); Eldorado Cañon (Cowles and Bogert, 1936, p. 38).

Uta stansburiana stansburiana

Baird and Girard

Brown-shouldered Lizard

Original description.—*Uta Stansburiana* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 69 (Salt Lake Valley, Utah). Stansbury's Expl. Surv. Vall. Great Salt Lake, 1852, p. 345, pl. 5, figs. 4–6.

Synonyms for Nevada.—*Uta stansburiana*, Yarrow, 1883, p. 56.

Uta stansburiana nevadensis, Ruthven and Gaige, 1915, p. 18.

Range.—Eastern Oregon, southern Idaho, northern California and Nevada, and most of Utah.

Occurrence in Nevada.—Record stations are nearly all in the northwestern part of the state, north of Fish Lake Valley, Esmeralda County. This lizard is usually confined to the near vicinity of rocks or bushes where it can reach cover quickly when disturbed.

Nevada localities (Fig. 12) (135 specimens in Museum of Vertebrate Zoology).—

Washoe County: Smoke Creek, 1 mile from California line (Mus. Vert. Zool.); Pyramid (Calif. Acad. Sci.); Sutcliffe (Calif. Acad. Sci.; U. S. N. M.); Anaho Island (Calif. Acad. Sci.); Derby (Stan. Univ.); Little High Rock Cañon (Mus. Vert. Zool.); Truckee River, 12 miles northwest of Wadsworth (Mus. Vert. Zool.); Big Bend of Truckee River (U. S. N. M.); east of Reno (U. S. N. M.).

Storey County: Virginia City.

Lyon County: Mason Valley, 12 miles east of Wellington (Mus. Vert. Zool.); Lincoln Highway, 22 and 29 miles west of Fallon (Mus. Vert. Zool.); West Walker River, 12 miles south of Yerington (Mus. Vert. Zool.).

Humboldt County: Virgin Valley (Mus. Vert. Zool.); Big Creek Ranch (Mus. Vert. Zool.); Alder Creek (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.).

Elko County: Cortez Range, near Carlin (Univ. Mich.); Moleen Cañon (Univ. Mich.); Piñon Cañon (Univ. Mich.); 8 miles southwest of Wendover, Utah, 4,700 feet (Mus. Vert. Zool.).

Pershing County: 2 miles west of Toulon (Mus. Vert. Zool.); 15 miles west of Lovelock, 5,100 feet (Mus. Vert. Zool.); south base Granite Peak, East Range (Mus. Vert. Zool.).

Churchill County: Hazen (Univ. Mich.); 5 miles north of Fallon (Mus. Vert. Zool.); 2 miles east of Sand Spring (U. S. N. M.); 7 miles east of Frenchman's Station (U. S. N. M.).

Lander County: Smoky Valley, between Birch and Kingston creeks (Mus. Vert. Zool.); Clear Creek, 6,500 feet (Mus. Vert. Zool.).

Eureka County: 12 miles south of Eureka (Mus. Vert. Zool.).

White Pine County: 8 miles west of Illipah (Burt, 1933, p. 236); Mt. Moriah near Smith Creek Cave (Mus. Vert. Zool.).

Mineral County: East Walker River, 2 miles northwest of Morgan's Ranch (Mus. Vert. Zool.); 7 miles north of Schurz, 4,600 feet (Mus. Vert. Zool.); Endowment Mine (Mus. Vert. Zool.); Huntoon Valley, 6,700 feet (Mus. Vert. Zool.).

Esmeralda County: 7 miles north of Arlemont (Mus. Vert. Zool.); Arlemont (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.).

Nye County: Wisconsin Creek, 6,000 feet (Mus. Vert. Zool.); Ophir Creek, 6,500 feet (Mus. Vert. Zool.); Last Chance Creek, 6,000 feet (Mus. Vert. Zool.); South Twin River, 6,500 feet (Mus. Vert. Zool.); Pablo Creek, 6,400 feet (U. S. N. M.); Smoky Valley, 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); Round Mountain (U. S. N. M.); Tonopah (Calif. Acad. Sci.).

Richardson (1915, p. 412) on the basis mainly of specimens from western Nevada, characterized *Uta s. stansburiana* as having "small, rounded, and weekly carinated dorsal scales. The number of scales in a line from the interparietal plate to a point on the rump above the posterior surfaces of the thighs varies between 89 and 116. The average for 55 specimens is 103.4. Six males have a tail length ranging from 70 mm. to 77 mm., average 74+ mm. In five females the minimum length is 66 mm., the maximum 69 mm., and the average 67+ mm. The femoral pores likewise are fewer in number (average 13+) than in the other forms (= *stejnegeri* and *hesperis*)." That author considered *nevadensis* to be identical with *stansburiana*.

Uta stansburiana stejnegeri Schmidt

Brown-shouldered Lizard

Original description.—*Uta stansburiana stejnegeri*, Schmidt, Amer. Mus. Nov., no. 15, 1921, pp. 1–2 (Mouth of Dry Cañon, Alamogordo, Otero County, New Mexico).

Synonyms for Nevada.—*Uta stansburiana*, Stejneger, 1893, p. 175.

Uta stansburiana stansburiana, Cowles and Bogert, 1936, p. 38.

Range.—Southeastern California and southern Nevada east to western Texas and south to northeastern Lower California and northern Mexico.

Occurrence in Nevada.—Southern part of the state is occupied by this race which extends north along the eastern border as far as the 39th parallel and northwest as far as Tonopah. The northern boundary of the range has been drawn on the map somewhat arbitrarily, but it agrees fairly well with the treatment given this species by Van Denburgh (1922). The population in the southern end of the state is generally distributed throughout the deserts and the mountains.

Nevada localities (Fig. 12) (140 specimens in Museum of Vertebrate Zoology).—

White Pine County: Baker (Mus. Vert. Zool.); 4 miles northeast of Baker (Univ. Mich.); 4 miles northwest of Baker (U. S. N. M.).

Esmeralda County: Goldfield (Calif. Acad. Sci.).

Nye County: Rhyolite (Calif. Acad. Sci.); south end Kawich Mountains (Mus. Vert. Zool.); 2 miles southeast of Fairbanks Spring (Mus. Vert. Zool.); Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.); 2 miles northwest of Indian Spring, Belted Range (Mus. Vert. Zool.); 8 miles west of Tybo, 6,700 feet, Hot Creek Range (Mus. Vert. Zool.); 4 miles north of Hot Creek, Hot Creek Range (Mus. Vert. Zool.); Railroad Valley, 3 miles south of Nyala, 5,600 feet (Mus. Vert. Zool.); 7½ to 9 miles east of Cliff Spring, 6,000 feet (Mus. Vert. Zool.); Garden Valley, 8½ miles northeast of Sharp (Mus. Vert. Zool.); Ash Meadows (U. S. N. M.); Pahrump Valley (U. S. N. M.).

Lincoln County: Penoyer Valley, 9 miles southeast of Belted Peak (Mus. Vert. Zool.); 16 miles east of Groom Baldy, 4,600 feet (Mus. Vert. Zool.); Crystal Spring, and 1 mile northeast (Mus. Vert. Zool.); Ash Spring (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); Caliente (U. S. N. M.); 21 miles south of Caliente (Mus. Vert. Zool.); 1 mile west of Coyote Spring, 2,500 feet (Mus. Vert. Zool.); 6 miles northeast of Carp (Mus. Vert. Zool.).

Clark County: Mountain Spring, 5,600 feet, Charleston Mountains (U. S. N. M.); Kyle Cañon, 6,000 feet, Charleston Mountains (Mus. Vert. Zool.); Kyle Cañon, 4,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 38); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.); Virgin River (U. S. N. M.); 2 and 5 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); Saint Thomas (U. S. N. M.); Mesquite (San Siego Soc. Nat. Hist.); 3 miles south of Mesquite, 2,500 feet (Mus. Vert. Zool.); Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); Glendale (Klauber coll.); 3 miles northwest and 10 miles northeast of Las Vegas (Mus. Vert. Zool.); Las Vegas (Klauber coll.); Vegas Valley (U. S. N. M.); 19 miles south of Las Vegas (Mus. Vert. Zool.); 6 miles north of Searchlight (Mus. Vert. Zool.); 14 miles northeast of Searchlight (Mus. Vert. Zool.); Searchlight (Klauber, 1932, p. 122); Jean (Klauber, 1932, p. 122); 1 mile west of Jean (Mus. Vert. Zool.); Piute Valley, 1 mile north of California line (Klauber, 1932, p. 122); Colorado River, 25 miles above Boulder Dam (Mus. Vert. Zool.); vicinity of Boulder City (Cowles and Bogert, 1936, p. 38); Hiko Spring, 2,000 feet (Mus. Vert. Zool.); 2 miles northwest of Fort Mojave, 500 feet (Mus. Vert. Zool.).

The form of *Uta* which inhabits southern Nevada was described by Richardson (1915, p. 415) as follows: "Like *Uta stansburiana* Baird and Girard, but with larger and more heavily carinated and acutely pointed dorsal scales. The number of scales in a line from the interparietal plate on the head to a point on the back above the posterior surfaces of the thighs varies in 111 specimens from 78 to 103; average, 86.5. The general size is larger than that of *Uta stansburiana*, especially in the ratio of the hind leg to the length from snout to anus and in the tail length. The tail length in 6 males from the Colorado River, Arizona and California, ranges from 92.5 mm. to 104.5 mm.; average, 98.3 mm. In 8 females from the same region the minimum length is 71.5 mm., the maximum 81.5 mm., the average 76.2 mm., longer than in any typical *Uta stansburiana* ex-

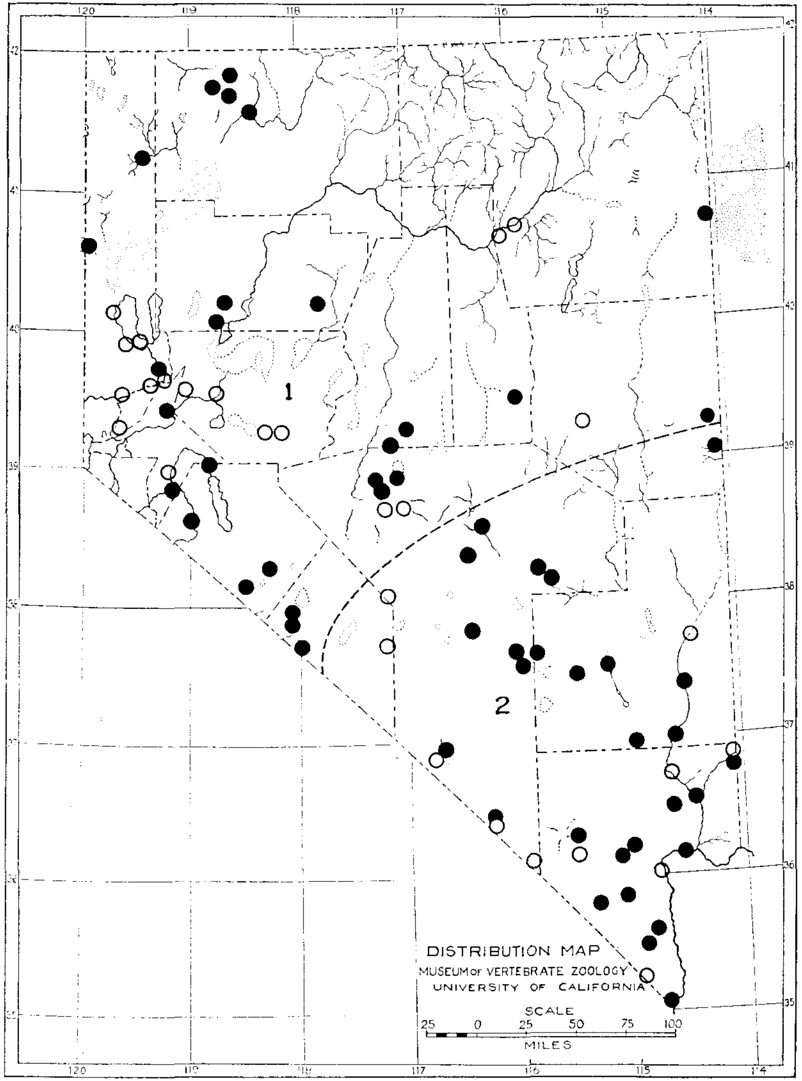
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FIG. 12. Distribution of *Uta stansburiana* in Nevada (1, *U. s. stansburiana*; 2, *U. s. stejnegeri*).

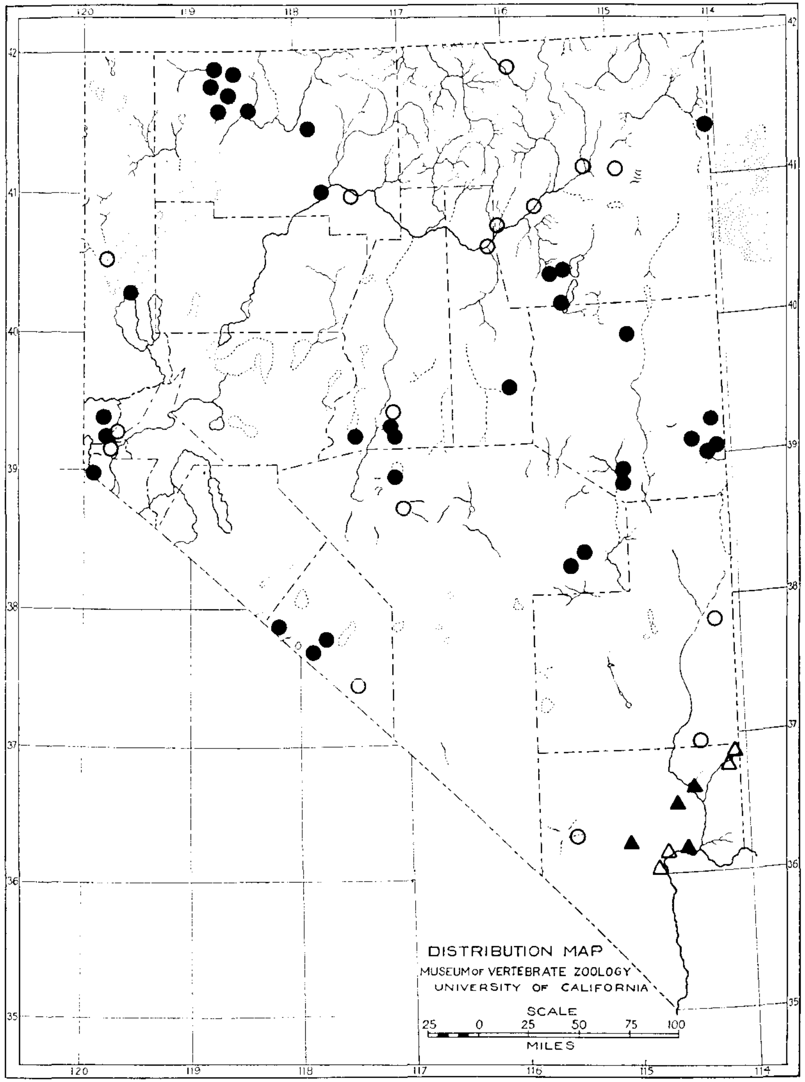
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FIG. 13. Distribution of *Sceloporus graciosus* (circles) and *Uta graciosa* (triangles) in Nevada.

amined. The femoral pores average 14+ on each thigh, a larger average number than is possessed by *Uta stansburiana.*"

Sceloporus graciosus graciosus

Baird and Girard

Sagebrush Lizard

Original description.—*Sceloporus graciosus* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 69 (Valley of Great Salt Lake, Utah).

Synonyms for Nevada.—*Sceloporus gracilis,* Yarrow, 1875, p. 576.

Sceloporus gratiosus, Yarrow, 1875, p. 576.
Sceloporus consobrinus, Yarrow, 1883, p. 61.
Sceloporus graciosus, Ruthven and Gaige, 1915, p. 21.
Sceloporus graciosus gracilis, Van Denburgh, 1922, p. 285.

Range.—Eastern Oregon and Nevada east to Wyoming and Colorado and south to northeastern Arizona and western Oklahoma.

Occurrence in Nevada.—This race occupies most of the state above the 4,500-foot level, except the extreme southern part. It has been taken as far south as the Charleston Mountains in Clark County. Over most of the state it occupies the valleys and flats between 5,000 and 6,500 feet; some places occurring as high as 8,000 feet. Most frequently it is found among stands of *Artemisia tridentata.* In general the habitat of this species in Nevada seems to be below that of the larger *S. occidentalis.* This is just the reverse of the condition in California, where the large species is more frequent in the valleys and low ground and the small one is restricted to the mountains.

Nevada localities (Fig. 13) (101 specimens in Museum of Vertebrate Zoology).—

Washoe County: Smoke Creek Desert (U. S. N. M.); Horse Cañon, Pahrum Peak (Mus. Vert. Zool.); Fox Cañon, 6 miles south of Pahrum Peak (Mus. Vert. Zool.); 2 miles west of Reno Hot Springs (Mus. Vert. Zool.); east side of Washoe Lake (Mus. Vert. Zool.).

Storey County: Virginia City (Van Denburgh, 1922, p. 285).

Ormsby County: Carson City (U. S. N. M.).

Douglas County: 3 miles southeast of Lake Tahoe (Mus. Vert. Zool.).

Humboldt County: Virgin Valley (Mus. Vert. Zool.); Thousand Creek (Mus. Vert. Zool.); Alder Creek, 5,000 and 6,000 feet (Mus. Vert. Zool.); Big Creek, 4,800 to 6,000 feet (Mus. Vert. Zool.); Big Creek Ranch (Mus. Vert. Zool.); Leonard Creek, 5,000 to 6,000 feet (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); Amos (Mus. Vert. Zool.); Winnemucca (Mus. Vert. Zool.); Golconda (U. S. N. M.).

Elko County: Mountain City (U. S. N. M.); Tecoma, 4,900 feet (Mus. Vert. Zool.); Wells (Calif. Acad. Sci.); Elko (Calif. Acad. Sci.; U. S. N. M.); Carlin (Calif. Acad. Sci.; U. S. N. M.); Deeth (U. S. N. M.); Harrison Pass R. S. (Mus. Vert. Zool.); Green Mountain Cañon, Ruby Mountains (Mus. Vert. Zool.); west side of Ruby Lake, 3 miles north of Elko County line (Mus. Vert. Zool.).

Lander County: Austin (Calif. Acad. Sci.); Big Creek Camp Ground (Mus. Vert. Zool.); Mahogany Cañon (Mus. Vert. Zool.); Kingston R. S. (Mus. Vert. Zool.); Peterson Creek, 6,500 feet, Shoshone Mountains (Mus. Vert. Zool.).

Eureka County: Cortez Mountains (Univ. Mich.); Palisade (Stan. Univ.); 8 miles west of Eureka (Mus. Vert. Zool.).

White Pine County: Antelope Springs (Van Denburgh, 1922, p. 278); Sacramento Pass, 10 miles from Osceola (Univ. Mich.); Cherry Creek, 6,800 feet (Mus. Vert. Zool.); Spring Valley, 6,000 feet, 5½ miles southwest of Osceola (Mus. Vert. Zool.); Deadman Creek and Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.); Lehman Cave (Mus. Vert. Zool.); Baker Creek, 6,600 to 7,500 feet (Mus. Vert. Zool.); Baker, 5,800 feet (Mus. Vert. Zool.); Water Cañon, 8 and 10 miles north of Lund (Mus. Vert. Zool.); White River Valley, 1 mile south of Lund (Mus. Vert. Zool.).

Esmeralda County: Chiatovich Creek, 7,000 and 8,200 feet (Mus. Vert. Zool.); Valcalda Spring (Mus. Vert. Zool.); 2 miles south of Piper Peak, 7,700 feet, Silver Peak Range (Mus. Vert. Zool.); Mount Magruder, 8,000 feet (U. S. N. M.).

Nye County: Smoky Valley, 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); Round Mountain (Calif. Acad. Sci.); Scofield Cañon, Grant Mountain (Mus. Vert. Zool.); Burned Corral Cañon, 6,700 feet, Quinn Cañon Mountains (Mus. Vert. Zool.).

Lincoln County: 15 miles east of Panaca (U. S. N. M.); Mormon Mountains (U. S. N. M.).

Clark County: Kyle Cañon, 5,000 to 8,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 38).

As was pointed out by Van Denburgh (1922, p. 276) the Nevada population of this species is intermediate in most characters between the races *graciosus* and *gracilis*. Typical examples of the former, from Utah, have larger dorsal scales and brighter coloration with dorsal and lateral blotches more distinct as compared with *gracilis* from Oregon and western California. Because the Nevada specimens seem to be nearer to *graciosus*, especially in coloration, all of them have been assigned here to that race. More material from the western border of the state might make it desirable to assign some specimens from there to the race *gracilis*.

The summary of measurements and scale counts tabulated below shows some structural characters of the Nevada population.

	Length snout to anus	Length of tail	Length hind leg	Femoral pores	Scales from interparietal to posterior surface of thigh
	36 males (measurements in mm.)				
Av.	54.31	75.85	38.27	14.56	52.71
Min.	48.4	62.2	32.7	12	44
Max.	62.4	95.0	44.4	19	61
	48 females				
Av.	54.94	72.35	37.29	14.20	53.66
Min.	45.7	59.9	29.4	10	44
Max.	64.1	88.3	42.0	18	61

In Elko County, Ruthven and Gaige (1915, p. 22) found this to be the most common and widely distributed lizard. It was found at altitudes between 5,000 and 7,500 feet, but most commonly at the lower levels. It was observed among rocks rarely, and then only where there was much soil, for it was found to be pre-eminently a ground form preferring a fine soil. They generally found this lizard beneath sage and other bushes where the coloration was protective. It climbed among the bushes to some extent, but when alarmed generally sought safety under dead brush or in a burrow. At night it buried itself in the loose soil. Females taken on July 4 contained large eggs; those taken on and after July 10 had none.

Females containing eggs were reported from the region of the Pine Forest Mountains, by Taylor (1912, p. 350) as collected on May 21, June 18, and June 25.

In Water Cañon, 8 miles north of Lund, White Pine County, on June 14, 1932, Boyers (MS) made observations on fighting of two individuals of this species. The two lizards darted off a small rock under a sage bush and rolled about six inches down the slope, hanging on to each other with their teeth. They separated and stalked around each other, with throat puffed out, belly lowered, and tail straight out behind, every few seconds displaying by raising and lowering the body by flexing all four legs at once. After a minute, one moved off down slope and left the other.

Sceloporus magister magister Hallowell

Rough-scaled Lizard

Original description.—*Sceloporus magister* Hallowell, Proc. Acad. Nat. Sci. Phila., vol. 7, 1854, p. 93 (near Fort Yuma, California).

Synonyms for Nevada.—*Sceloporus clarkii*, Yarrow and Henshaw, 1878, p. 1645.

Sceloporus clarki clarki, Yarrow, 1883, p. 63.
Sceloporus magister, Richardson, 1915, p. 418.

Range.—From western Nevada south to northern Lower California and from southern California to southern Utah.

Occurrence in Nevada.—The rough-scaled lizard is common in the southern and western parts of the state, below the 4,000-foot level. In the west it extends northward as far as Pyramid Lake, in the east as far as Caliente. Usually lives where there are trees and bushes among which it climbs.

Nevada localities (Fig. 14) (73 specimens in Museum of Vertebrate Zoology).—

Washoe County: North end of Pyramid Lake (Calif. Acad. Sci.; U. S. N. M.); near The Needles (Mus. Vert. Zool.); Sutcliffe (Calif. Acad. Sci.); The Willows (U. S. N. M.); Anaho Island (Calif. Acad. Sci.); Wadsworth (U. S. N. M.); Derby (Van Denburgh, 1922, p. 335).

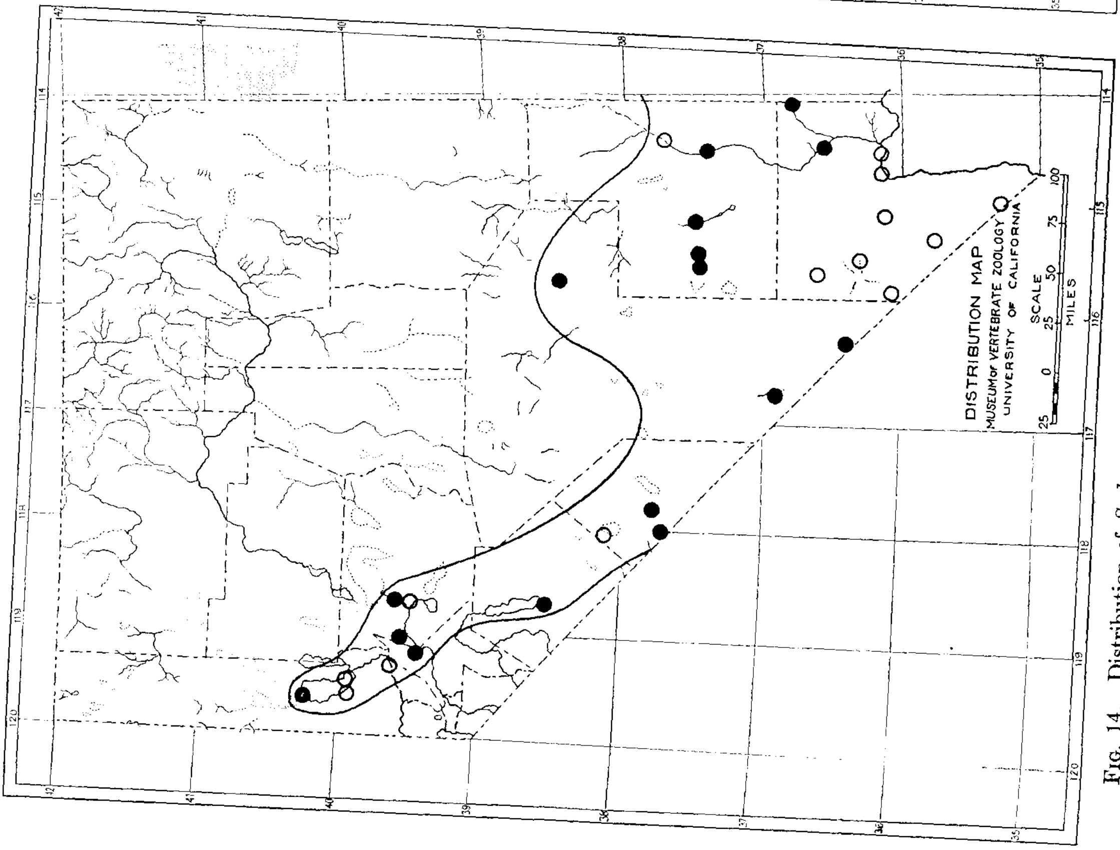
DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
25 0 25 50 75 100
MILES
42
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FIG. 14. Distribution of *Sceloporus magister magister* in Nevada.

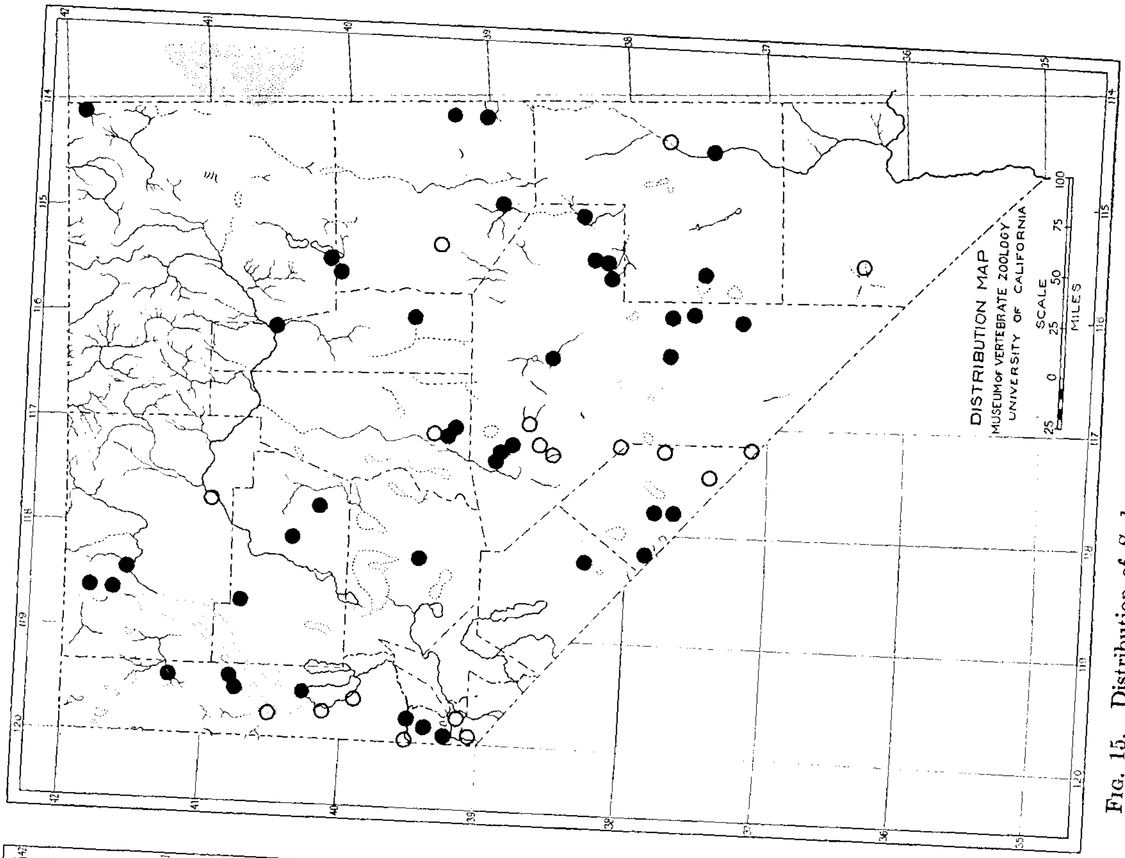
DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
25 0 25 50 75 100
MILES
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FIG. 15. Distribution of *Sceloporus occidentalis bi-seriatus* in Nevada.

Lyon County: Lincoln Highway, 22 miles west of Fallon (Mus. Vert. Zool.).

Churchill County: Hazen (Burt and Burt, 1929, p. 451); 6 miles west of Hazen (Mus. Vert. Zool.); 10 miles west and 5 miles north of Fallon (Mus. Vert. Zool.); 4 miles west of Fallon (U. S. N. M.); Fallon (U. S. N. M.); Sand Spring (Burt, 1933, p. 238).

Mineral County: 4 miles northwest of Hawthorne (Mus. Vert. Zool.).

Esmeralda County: Columbus (Van Denburgh, 1922, p. 335); Fish Lake (Mus. Vert. Zool.); 2 miles northwest of Cave Spring, 5,700 feet (Mus. Vert. Zool.); Grapevine Mountains (U. S. N. M.).

Nye County: Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.); Ash Meadows (U. S. N. M.); Ash Meadows, 3.2 miles west southwest of Devil's Hole (Mus. Vert. Zool.); Rhyolite (Calif. Acad. Sci.); Railroad Valley, 11 miles south of Lock's Ranch (Mus. Vert. Zool.).

Lincoln County: 9 and 16 miles east of Groom Baldy (Mus. Vert. Zool.); Crystal Spring (Mus. Vert. Zool.); ¾ mile west of Ash Spring (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); Pahranagat Mountains (U. S. N. M.); Caliente (Calif. Acad. Sci.); Meadow Valley, 21 miles south of Caliente (Mus. Vert. Zool.).

Clark County: Pahrump Valley (U. S. N. M.); Indian Spring Valley (U. S. N. M.); Kyle Cañon, 4,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 38); Kaolin (Mus. Vert. Zool.); Overton (Cowles and Bogert, 1936, p. 38); Bunkerville (U. S. N. M.); Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); Vegas Valley (U. S. N. M.); Callville (U. S. N. M.); Jean (Klauber, 1932, p. 122) Piute Valley, 1 mile north of California line (Klauber, 1932, p. 122); Colorado River, 25 miles above Boulder Dam (Borell, spec.).

Stejneger (1893, p. 179) was first to find characters to distinguish *S. clarkii* and *S. magister*. He decided that the most distinctive character was the difference in the spiny scales which protect the anterior border of the ear opening. He wrote that "the constancy of the character was soon verified in a large series of specimens, as well as the concomitancy of the presence or absence of dusky markings on the dorsal aspect of the forearm and hand."

Later, Burt (1935, p. 275) concluded that these forms show no constancy "in their described characters when examined in large numbers, the oldest males tending to have better developed ear denticulations than the rest of the population. Like other reptile species of the West, the ground color of the back is darker at higher altitudes and lighter (or more brownish) about the desert floor."

The climbing habits of this lizard as observed in Washoe County were reported by Richardson (1915, p. 419). Near Pyramid Lake he found it in bushes along the Truckee River, on tufa cliffs near the lake, on volcanic rocks in the hills, and along the lake shore, but never far out on the desert. At Derby it was found in two types of surroundings—in and about bushes near the river where it was abundant, and on rocky hillsides. He noted that as individuals ran from bush to bush, they lifted their tails above the level of the body much in the manner of gridiron-tailed lizards. It was seen basking on rocks with the smaller fence lizard. Van Denburgh and Slevin (1921, p. 34) report that specimens taken in the vicinity of Pyramid Lake, in July, were "usually found on the ground under thorn bushes" and they "were bright green and very wild." All specimens they obtained from Rhyolite and Caliente were found on rocks on the hillsides.

In the vicinity of Crystal Spring, Pahranagat Valley, in May 1932, this species was abundant near the creek mostly among bushes or climbing in the cottonwoods. One was caught under a board at the base of a cottonwood. One was shot on a willow and another in leaves under an *Atriplex* bush. Fitch (MS) observed the species in this vicinity on rocks and fence posts.

Merriam (in Stejneger, 1893, p. 182) observed that unlike most of the lizards inhabiting the same region, this one does not run about on the open desert, but lives on the tree yuccas, the ruins of stone or adobe dwellings, the nests of wood rats, and other objects that afford it shelter and protection. In Pahranagat Valley he found it abundant about the ruins of stone houses and along the faces of cliffs. He found both insects and flowers in the stomachs.

Sceloporus occidentalis bi-seriatus

Hallowell

Fence Lizard

Original description.—*Sceloporus bi-seriatus* Hallowell, Proc. Acad. Nat. Sci. Phila., vol. 7, 1854, p. 93 (El Paso Creek and Tejon Valley, Kern County, California).

Synonyms for Nevada.—*Sceloporus undulatus* subspecies *undulatus*, Yarrow, 1875, p. 573.

Sceloporus smaragdinus, Yarrow, 1883, p. 62.

Sceloporus undulatus thayeri, Yarrow, 1883, p. 60.

Sceloporus biseriatus, Richardson, 1915, p. 421.

Sceloporus occidentalis biseriatus, Van Denburgh and Slevin, 1921, p. 34.

Sceloporus undulatus bi-seriatus, Burt, 1933, p. 238.

Sceloporus undulatus elongatus, Burt, 1933, p. 243.

Range.—From eastern Oregon and southern Idaho south to northern Lower California and from southern California to Wyoming and Texas.

Occurrence in Nevada.—This race of fence lizard is abundant throughout the state except the extreme southern part. Records show it to be present mainly in the mountains above 4,000 feet; they extend as high at least as 9,000 feet.

Nevada localities (Fig. 15) (215 specimens in Museum of Vertebrate Zoology).—

Washoe County: Little High Rock Cañon (Mus. Vert. Zool.); Rock Creek, 5,000 feet, Granite Mountains (Mus. Vert. Zool.); 10 miles north-northwest of Deephole, 5,150 feet (Mus. Vert. Zool.); Smoke Creek Desert (U. S. N. M.); Horse Cañon, Pahrum Peak (Mus. Vert. Zool.); 6 miles south of Pahrum Peak (Mus. Vert. Zool.); Sutcliffe (Calif. Acad. Sci.; U. S. N. M.); The Willows (U. S. N. M.); Pyramid (Calif. Acad. Sci.); Verdi (Calif. Acad. Sci.; U. S. N. M.); Reno (Calif. Acad. Sci.); 10 miles east of Reno, 4,500 feet (Mus. Vert. Zool.); 2 miles west of Reno Hot Springs (Mus. Vert. Zool.); Galena Creek, 6,500 feet (Mus. Vert. Zool.); 1 mile north of Incline (Mus. Vert. Zool.).

Ormsby County: Carson City (U. S. N. M.).

Douglas County: Glenbrook (Calif. Acad. Sci.; U. S. N. M.).

Humboldt County: Virgin Valley (Mus. Vert. Zool.); Big Creek Ranch (Mus. Vert. Zool.); Limestones (Mus. Vert. Zool.); Red hills, Quinn River Crossing (Mus. Vert. Zool.); 4 miles east of Winnemucca (Univ. Mich.).

Elko County: Goose Creek, 2 miles west of Utah line (Mus. Vert. Zool.); west side of Ruby Lake (Mus. Vert. Zool.); Ruby Mountains (Calif. Acad. Sci.).

Pershing County: 8 miles south of Sulphur, 4,350 feet (Mus. Vert. Zool.); El Dorado Cañon, 6,000 feet, Humboldt Range (Mus. Vert. Zool.); east side Granite Peak, East Range (Mus. Vert. Zool.).

Churchill County: Mountain Well (Mus. Vert. Zool.).

Lander County: Austin (Calif. Acad. Sci.); Big Creek, 6,700 feet (Mus. Vert. Zool.); Kingston Creek, 7,000 and 7,500 feet (Mus. Vert. Zool.); Clear Creek, 6,500 feet (Mus. Vert. Zool.).

Eureka County: 3½ miles southeast of Palisade (Mus. Vert. Zool.); 8 miles west of Eureka (Mus. Vert. Zool.).

White Pine County: Willow Creek, 2 miles south of county line (Mus. Vert. Zool.); 8 miles west of Illipah (U. S. N. M.); Smith Creek Cave, near Mt. Moriah (Mus. Vert. Zool.); Lehman Cave (Mus. Vert. Zool.); Baker Creek, 7,500 feet (Mus. Vert. Zool.); Water Cañon, 8 miles north of Lund (Mus. Vert. Zool.).

Mineral County: Endowment Mine (Mus. Vert. Zool.).

Esmeralda County: Chiatovich Creek, 7,000 feet (Mus. Vert. Zool.); 2 miles south of Piper Peak, 7,700 feet (Mus. Vert. Zool.); Cave Spring (Mus. Vert. Zool.); Goldfield (Calif. Acad. Sci.); Mount Magruder (U. S. N. M.); Grapevine Mountains (U. S. N. M.).

Nye County: Wisconsin Creek 7,800 to 9,000 feet (Mus. Vert. Zool.); Ophir Creek, 6,500 feet (Mus. Vert. Zool.); South Twin River, 6,500 and 7,000 feet (Mus. Vert. Zool.); Mohawk R. S. (Mus. Vert. Zool.); Pablo Creek (U. S. N. M.); Peavine Creek, 6,000 feet (U. S. N. M.); Round Mountain (Calif. Acad. Sci.); Jefferson R. S. (U. S. N. M.); Tonopah (Calif. Acad. Sci.); 8 to 9 miles east of Cliff Spring, 6,100 feet (Mus. Vert. Zool.); Garden Valley, 8½ miles northeast of Sharp (Mus. Vert. Zool.); Belted Range, 2 miles northwest of Indian Spring (Mus. Vert. Zool.); 5 miles west of White Rock Spring (Mus. Vert. Zool.); near Oak Spring, 5,700 feet (Mus. Vert. Zool.); south end of Kawich Mountains (Mus. Vert. Zool.); White River Valley, 14 miles southwest of Sunnyside (Mus. Vert. Zool.); Hot Creek Range, 4 miles north of Hot Creek, 6,400 feet (Mus. Vert. Zool.); Railroad Valley, 3 miles south of Nyala, 5,600 feet (Mus. Vert. Zool.); Burned Corral Cañon, 6,500 feet, Quinn Cañon Mountains (Mus. Vert. Zool.).

Lincoln County: Southwest base of Groom Baldy, 7,200 feet (Mus. Vert. Zool.); Caliente (Calif. Acad. Sci.); Meadow Valley, 21 miles south of Caliente (Mus. Vert. Zool.).

Clark County: Charleston Mountains (U. S. N.

M.); Charleston Park, 7,800 feet (San Diego Soc. Nat. Hist.); Kyle Cañon and Harris Spring, 4,000 to 6,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 38); Kyle Cañon, 6,000 feet (Mus. Vert. Zool.).

The systematic relationships of *S. o. bi-seriatus* in eastern Nevada have been discussed by Burt (1933, p. 240) who decided that the numbers of scales from the occiput to the base of the tail provided the most constant difference between *bi-seriatus* and *elongatus*. On this basis he concluded that "if we arbitrarily regard all of these lizards having 42 or less than 42 scales from the occiput to the base of the tail as *bi-seriatus* and those having more than this number as *elongatus*, a zone of intergradation between the two forms becomes evident in eastern Nevada and western Utah where the ranges of the two subspecies meet and overlap. This phenomenon is noted in the present specimens from White Pine County, Nevada, and an intergrade with a count of 43 was collected in Eureka County to the west. Throat patches of intergrades in Nevada may be united as in *bi-seriatus* instead of separated as in *elongatus* of the west and south."

My own examination of specimens has failed to demonstrate the close relationship of these two forms implied in the quotation just given. To me the color pattern, especially the blue throat patches, is more diagnostic than number of dorsal scales. The specimens I have seen bear out Van Denburgh's (1922) treatment of these two lizards. However, it would not be surprising if further material from some place eastward from Nevada showed closer relation between the two forms.

Observations on the behavior of fence lizards in the breeding season were made on June 13, 1932, by Fitch (MS) in Water Cañon, 8 miles north of Lund, White Pine County. A male on a large boulder near the camp was feeding on flies which it caught by sudden rushes before they had time to move. A dead male lizard of the same species attached to a fine wire was dragged over the surface of the rock. The live one immediately ran to it and bit its side, and then followed it away from the rock, running alongside and nipping at it.

Several yards distant another male came into view, pursuing a female which it overtook and caught by grasping in its mouth a fold of skin about an inch behind the axilla. These lizards lost their foothold on the slanting rock surface and rolled several feet, finally falling to the ground. After a short struggle, the female freed herself and escaped from the pursuing male.

By maneuvering the dead lizard the first male was attracted to the smaller one that had been seen with the female. The dead one then was removed and the first male transferred his attention to the second one. His actions were the same as had been shown toward the dead one. Standing high off the ground, with body compressed and showing to advantage the bright blue patches on throat and abdomen, it moved jerkily toward the other one. The second male at first displayed in a similar manner, but when the first one approached and nipped at it, it retreated and made an almost continuous run to a ledge of rock about 30 feet away.

One method of fighting observed here was for one animal to run past another in a direction opposite to its course and to bite at its legs or abdomen as it passed. At the same time the aggressor would move the tail and hind quarters quickly and strike a sharp blow on its opponent's head. This method of attack appeared to be just as effective as biting.

When a mirror was placed on a rock near one of the males its reaction to the image was like that toward another live lizard, except that it lost interest in about two minutes.

Several times a fighting male suddenly broke off its attack, when no cause for disturbance was detected, and ran to hide in a crevice; each time it returned after a few seconds.

When the dead male was dragged near the female, the latter stood high with tail elevated and moved with a half running, half hopping gait, turning to nip at the male when it was brought too close.

On June 28, 1934, Fitch (MS) found a pair of fence lizards copulating on a rock near the Truckee River, 5 miles west of Reno. This is evidence of a difference of about two months in the breeding cycle here and on the coast.

Throughout northwestern Nevada, this lizard was found to be a rock-dwelling form by Richardson (1915, p. 421). Two females taken on May 24 at Reno, held 7 and 10 eggs.

The restriction to rocky places was also noted by Ruthven and Gaige (1915, p. 20) in the upper Humboldt Valley, where they found fence lizards in such places as cliffs, outcrops, talus slopes, and stream beds. They observed that the lizards on warm days, were quite common everywhere over the rocks until the hottest part of the day, when they retired to the shaded side. Large females obtained on and before July 12 contained large eggs about ready to be laid; those collected on July 22 had deposited their eggs. On August 14, young ones, several days old, were seen. One that was captured measured 55 mm. in total length. They ran over the ground and small rocks at the base of a cliff and, when alarmed, sought concealment under loose stones.

Courtship behavior in this species was watched on June 1, 1932, in the hills at 5,900 feet, east of Cliff Spring, Nye County (Fitch, MS). Here there were juniper trees and a few piñons on the rocky ground. Numerous fence lizards were seen on the rocks. A male and a female were seen sunning themselves on a large boulder. As the observer approached slowly they moved from one boulder to another, both always stopping on top of the same rock and within a few inches of each other. Several times the male displayed near the female, arching his back, raising his tail, advancing with short, jerky movements and standing high off the surface of the rock with throat pouch extended. Several times he moved up and pushed the female with his snout. At such times the female sidled away.

Phrynosoma douglassii ornatissimum (Girard)

Pigmy Horned-toad

Original description.—*Tapaya ornatissima* Girard, U. S. Expl. Exped., Herp., 1858, p. 396 (mountainous region of New Mexico).

Synonyms for Nevada.—*Phrynonsoma douglassii* subspecies *douglassii*, Yarrow, 1875, p. 580.

Phrynosoma douglassi douglassi, Yarrow, 1883, p. 69.

Phrynosoma douglassii hernandesi, Richardson, 1915, p. 423.

Phrynosoma hernandesi, Ruthven and Gaige, 1915, p. 23.

Occurrence in Nevada.—Specimens are available from several localities in the northeast part of the state, west on the north side of the Humboldt River as far as the Santa Rosa Mountains, and south near the eastern border to about 39° N.

Nevada localities (Fig. 16) (9 *specimens in Museum of Vertebrate Zoology*).—

Humboldt County: Martin Creek R. S., Santa Rosa Mountains (Mus. Vert. Zool.).

Elko County: Mountain City (U. S. N. M.); Cobb Creek, 6 miles southwest of Mountain City, 6,550 feet (Mus. Vert. Zool.); Marys River, 22 miles north of Deeth (Mus. Vert. Zool.); near Deeth (Van Denburgh, 1922, p. 381); Halleck (U. S. N. M.); 3 miles south of Halleck (U. S. N. M.); Carlin (Univ. Mich. Mus.); James Cañon (Univ. Mich. Mus.).

White Pine County: 7 miles southeast of Hobson P. O. (Mus. Vert. Zool.); Water Cañon, 8 miles north of Lund (Mus. Vert. Zool.).

The record of this species from 2 miles north of Fernley (Burt and Burt, 1929, p. 454) apparently was based on a specimen now in the University of Michigan collection. I examined this specimen on October 8, 1933, and found it to be a young individual of *P. platyrhinos*. The locality is more than 160 miles from the nearest one listed above.

The pigmy horned-toads were found by Ruthven and Gaige (1915, p. 24) in Elko County, during the warmer parts of the day. At night they burrowed beneath the surface of the ground. The adults kept close to the shelter of bushes where their broken coloration was protective. The young ones with even coloration were observed more often in the open. Females taken on July 26, contained embryos. By August 7 and 8 all adult females had given birth to their young which were found in numbers.

Phrynosoma platyrhinos Girard

Desert Horned-toad

Original description.—*Phrynosoma platyrhinos* Girard, Stansbury's Expl. Surv. Vall. Great Salt Lake, 1852, pp. 361, 363, pl. 7, figs. 1-5 (Great Salt Lake Valley, Utah).

Synonyms for Nevada.—*Phrynosoma maccalli*, Yarrow, 1883, p. 65.

Phrynosoma platyrhinum, Yarrow, 1883, p. 65.

Phrynosoma douglassii ornatissimum, Burt and Burt, 1929, p. 454.

Phrynosoma platyrhinos platyrhinos, Cowles and Bogert, 1936, p. 38.

Range.—From Washington and Idaho south to northeastern Lower California and from eastern California to western Utah.

Occurrence in Nevada.—This horned toad is common in the valleys and flat areas over most of the state above the 2,000-foot level. Places of record are as high as 6,500 feet, and most of them are above 4,000 feet. The soil over most of this lizard's range is sandy or gravelly.

Nevada localities (Fig. 16) (253 specimens in Museum of Vertebrate Zoology).—

Washoe County: High Rock Cañon (Mus. Vert Zool.); Little High Rock Cañon (Mus. Vert

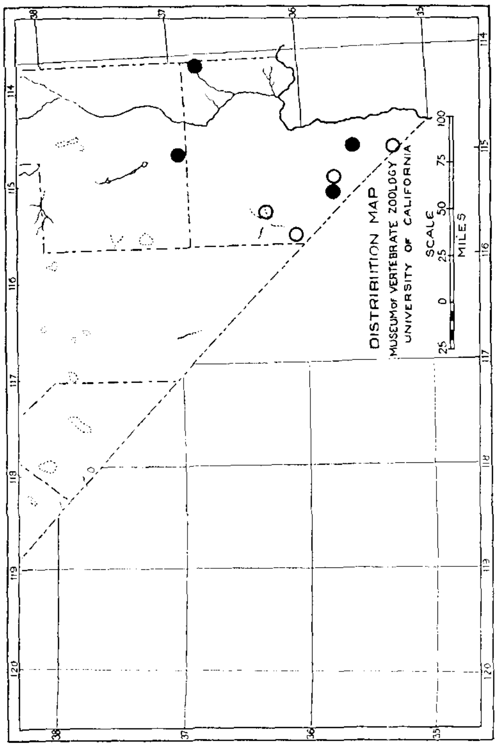
DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
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FIG. 17. Distribution of *Xantusia vigilis* in southern Nevada.

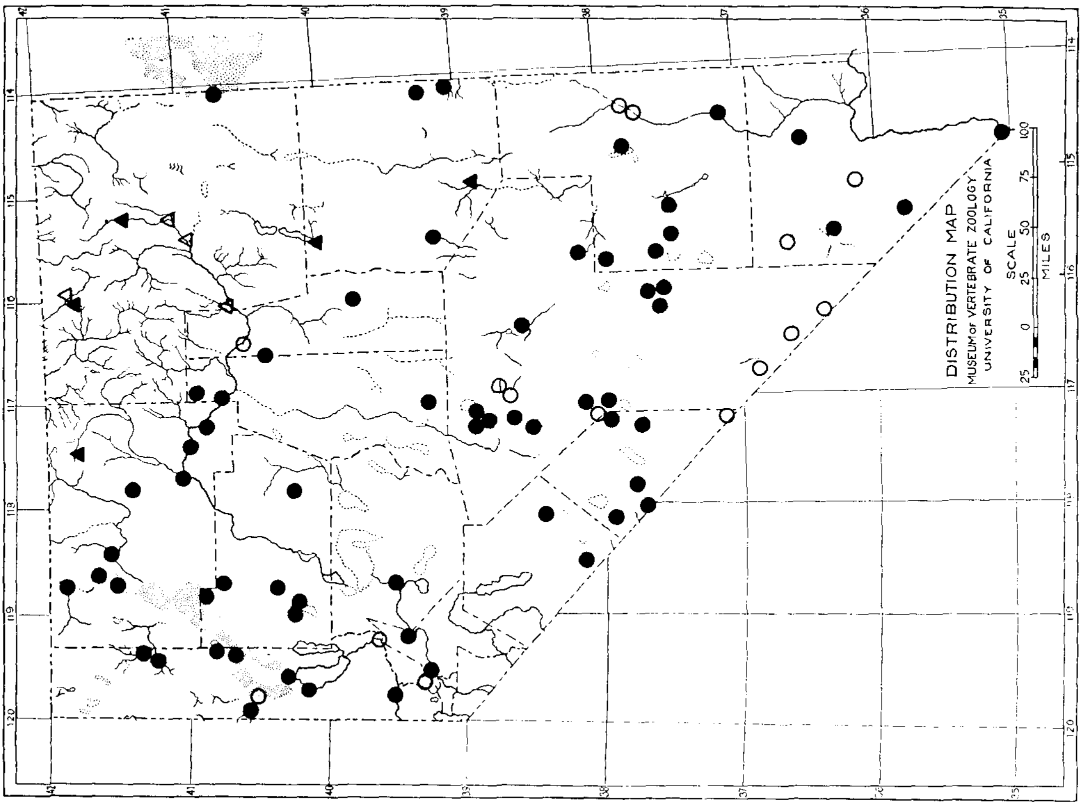
DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
25 0 25 50 75 100
MILES
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FIG. 16. Distribution of *Phrynosoma douglassii ornatissimum* (triangles) and *Phrynosoma platyrhinos* (circles) in Nevada.

Zool.); Smoke Creek, 3,900 feet (Mus. Vert. Zool.); 4½ miles northeast of Flanigan, 4,100 feet (Mus. Vert. Zool.); 1 mile northeast of Gerlach, 4,000 feet (Mus. Vert. Zool.); 2½ miles east and 11 miles north of Gerlach (Mus. Vert. Zool.); 4 miles west of Pahrum Peak (Mus. Vert. Zool.); 1 mile north of Pyramid (Mus. Vert. Zool.); Pyramid Lake (Calif. Acad. Sci.; U. S. N. M.); Reno (Calif. Acad. Sci.); east of Reno (U. S. N. M.); 10 miles east of Reno (Mus. Vert. Zool.); Smoke Creek Desert (U. S. N. M.); Wadsworth (U. S. N. M.).

Storey County: Virginia City (U. S. N. M.).

Lyon County: 2 miles north of Fernley (Univ. Mich.); Lincoln Highway, 22 miles west of Fallon (Mus. Vert. Zool.); 6½ miles east of Dayton (Mus. Vert. Zool.).

Humboldt County: Limestones (Mus. Vert. Zool.); Thousand Creek Basin (Mus. Vert. Zool.); Leonard Creek (Mus. Vert. Zool.); Big Creek, 4,350 and 5,000 feet (Mus. Vert. Zool.); near Amos P. O. (Mus. Vert. Zool.); Big Creek (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); 5 miles south of Quinn River Crossing, 4,000 feet (Mus. Vert. Zool.); 5 miles northeast and 1 mile south of Golconda (Mus. Vert. Zool.); Golconda (U. S. N. M.); 26 miles northwest of Battle Mountain (Mus. Vert. Zool.); 7 miles north of Winnemucca (Mus. Vert. Zool.).

Elko County: 3 miles southwest of Wendover, Utah (Mus. Vert. Zool.); head of Humboldt River (U. S. N. M.).

Pershing County: Buena Vista Valley, 4,150 feet, 10 miles east and 3 miles south of Fanning (Mus. Vert. Zool.); 3 miles southwest of Vernon, 4,300 feet (Mus. Vert. Zool.); 8 miles south of Sulphur, 4,350 feet (Mus. Vert. Zool.); 10 miles west and 6 miles north of Sulphur, 4,000 feet (Mus. Vert. Zool.); 21 miles west and 2 miles north of Lovelock, 4,000 feet (Mus. Vert. Zool.); 30 miles west and 4 miles north of Lovelock, 4,300 feet (Mus. Vert. Zool.).

Churchill County: 5 miles north of Fallon (Mus. Vert. Zool.).

Lander County: 14 miles north of Battle Mountain (Mus. Vert. Zool.); 3 miles south of Izenhood (Mus. Vert. Zool.); Smoky Valley, between Birch and Kingston creeks (Mus. Vert. Zool.); 8 miles northeast of Tenabo (Mus. Vert. Zool.).

Eureka County: Beowawe (U. S. N. M.); 4 miles southeast of Romano, Diamond Valley (Mus. Vert. Zool.); 12 and 16 miles northeast of Tenabo (Mus. Vert. Zool.).

White Pine County: Near Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.); near Baker (Mus. Vert. Zool.; U. S. N. M.); 2½ miles southwest of Hamilton, 7,600 feet (Mus. Vert. Zool.).

Mineral County: Huntoon Valley, 5,700 feet (Mus. Vert. Zool.); Mina.

Esmeralda County: 7 miles north of Arlemont, 5,500 feet (Mus. Vert. Zool.); Arlemont (Mus. Vert. Zool.); 2½ miles southeast of Dyer (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.); Cave Spring (Mus. Vert. Zool.); 10 and 15 miles south of Tonopah (Mus. Vert. Zool.); 13½ miles northwest of Goldfield (Mus. Vert. Zool.); Goldfield (Calif. Acad. Sci.); Grapevine Mountains, 4,200 feet (U. S. N. M.).

Nye County: Wisconsin Creek, 6,000 feet (Mus. Vert. Zool.); North of Twin River, 6,000 feet (Mus. Vert. Zool.); South Twin River, 6,500 feet (Mus. Vert. Zool.); Pablo Creek, 6,200 feet (U. S. N. M.); Peavine Creek, 6,000 feet (U. S. N. M.); Smoky Valley, 5 miles south and 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); Jefferson Creek, 6,300 feet (U. S. N. M.); Round Mountain, 6,300 feet (U. S. N. M.); Ralston Valley, 15½ miles northeast of Tonopah, 5,800 feet (Mus. Vert. Zool.); Tonopah (Calif. Acad. Sci.); 8 miles southeast of Tonopah (Mus. Vert. Zool.); near Indian Spring, Belted Range (Mus. Vert. Zool.); 1 mile south of Big Dry Lake, Kawich Valley; 7½ and 8 miles east of Cliff Spring, 5,900 feet (Mus. Vert. Zool.); Railroad Valley, 3 miles south of Nyala, 5,600 feet (Mus. Vert. Zool.); Hot Creek Valley 2 to 10 miles north of Hot Creek, 5,900 feet (Mus. Vert. Zool.); Rhyolite (Calif. Acad. Sci.); Amargosa Desert (U. S. N. M.); Ash Meadows (U. S. N. M.).

Lincoln County: Penoyer Valley, 14 miles north northwest of Groom Baldy (Mus. Vert. Zool.); 9 miles east of Groom Baldy, 5,500 feet (Mus. Vert. Zool.); Hancock Pass, west of Crystal Spring (Mus. Vert. Zool.); near Crystal Spring (Mus. Vert. Zool.); north end of Penoyer Valley (Mus. Vert. Zool.); 20 miles southwest of Pioche (Mus. Vert. Zool.); Panaca (U. S. N. M.); 21 miles west of Panaca (Mus. Vert Zool.); Caliente (Calif. Acad. Sci.); 4 miles northeast of Carp (Mus. Vert. Zool.).

Clark County: Indian Spring Valley (U.S.N.M.) 12 miles east of Charleston Park, 4,400 feet (Mus. Vert. Zool.); Las Vegas (Calif. Acad Sci.; U. S. N. M.); 2 miles south of Jean (Mus Vert. Zool.); 1½ miles northwest of For Mojave, 500 feet (Mus. Vert. Zool.); Hik

Spring, 2,200 feet, Dead Mountains (Mus. Vert. Zool.); Valley of Fire, 15 miles southeast of Crystal (Mus. Vert. Zool.); Boulder City (Cowles and Bogert, 1936, p. 39).

In the northwestern part of the state Richardson (1915, p. 423) observed this lizard on the desert among low bushes. In attempting to escape it ran beneath the bushes rather than into mammal burrows. On a long run it often raised its tail above the level of the sand. Two stomachs contained ants, beetles, and insect larvae. Three females captured at the end of May, and June 2 and 9, held 13, 9, and 13 eggs.

Taylor (1912, p. 351) found this horned-toad to be more common near the foothills of the Pine Forest Mountains than away from them on the open desert. The animals were found on sandy, on loamy, and on sun-baked hard soil. One, when picked up, opened its mouth and made a hissing sound. Copulation was noted on June 10 and on June 14 a female containing ten eggs was captured.

At 6 p. m. on July 31, 1934, five small horned-toads, apparently all members of a single brood were found by D. H. Johnson (MS) one mile southeast of Wadsworth, 4,200 feet, Lyon County. The animals were scattered over a single square yard of a level and sandy abandoned field then covered with Russian thistles. They were attempting to find cover beneath the plants.

Near Crystal Spring, Lincoln County, Fitch (MS) found a horned-toad sunning itself at 5:45 a. m. on May 19, 1932.

HELODERMATIDAE

Heloderma suspectum Cope

Gila Monster

Original description.—*Heloderma suspectum* Cope, Proc. Acad. Nat. Sci. Phila., 1869, p. 5 (Sierra de la Union, Arizona ["Sonora"]).

Range.—Southern Nevada and Utah, Arizona and Sonora.

Occurrence in Nevada.—Records are all in the southeastern corner of the state, as far west as Las Vegas and as far north as Meadow Valley, but mostly in the vicinity of the Virgin River. So few specimens have been discovered as to indicate a small population likely to become exterminated within the state.

Nevada localities (No specimens in Museum of Vertebrate Zoology).—

Lincoln County: Meadow Valley (Van Denburgh, 1922, p. 473).

Clark County: Virgin River, 8 miles below Bunkerville (U. S. N. M.); Overton (Cowles and Bogert, 1936, p. 39); Saint Thomas (Van Denburgh, 1922, p. 473); Las Vegas (Van Denburgh, 1922, p. 473).

XANTUSIIDAE

Xantusia vigilis Baird

Desert Night Lizard

Original description.—*Xantusia vigilis* Baird, Proc. Acad. Nat. Sci. Phila., 1858 [1859], p. 255 (Fort Tejon, California).

Range.—Southeastern California, southern Nevada, and northeastern Lower California.

Occurrence in Nevada.—Specimens represent localities in the southern part of the state, as far north as Coyote Spring, near 37° N., and at altitudes up to 4,000 feet. Individuals have been captured about the dead limbs and stumps of Joshua trees and Spanish dagger, more frequently the latter.

Nevada localities (Fig. 17) (34 specimens in Museum of Vertebrate Zoology).—

Lincoln County: Coyote Spring, 2,500 feet (Mus. Vert. Zool.).

Clark County: Pahrump Valley (U. S. N. M.); Kyle Cañon, about 4,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 39); 10 miles east of Jean (Cowles and Bogert, 1936, p. 39); 5 miles north of Jean (Klauber, 1932, p. 123); 1 mile west of Jean (Mus. Vert. Zool.); Piute Valley, 1 mile north of California line (Klauber, 1932, p. 123); 14 miles north of Searchlight, 3,500 feet (Mus. Vert. Zool.); 3 miles south of Mesquite, 2,500 feet (Mus. Vert. Zool.).

TEIIDAE

Cnemidophorus tesselatus tesselatus (Say)

Whip-tailed Lizard

Original description.—*Ameiva tesselata* Say, Long's Exp. Rocky Mts., vol. 2, 1823, p. 50 (Arkansas River, near Castle Rock Creek, Colorado).

Synonyms for Nevada.—*Cnemidophorus tigris*, Richardson, 1915, p. 425.

Cnemidophorus tessellatus tessellatus, Cowles and Bogert, 1936, p. 39.

Range.—Eastern Oregon and southern Idaho south to southern Coahuila, Mexico and from California to western Texas.

Occurrence in Nevada.—Whip-tailed lizards

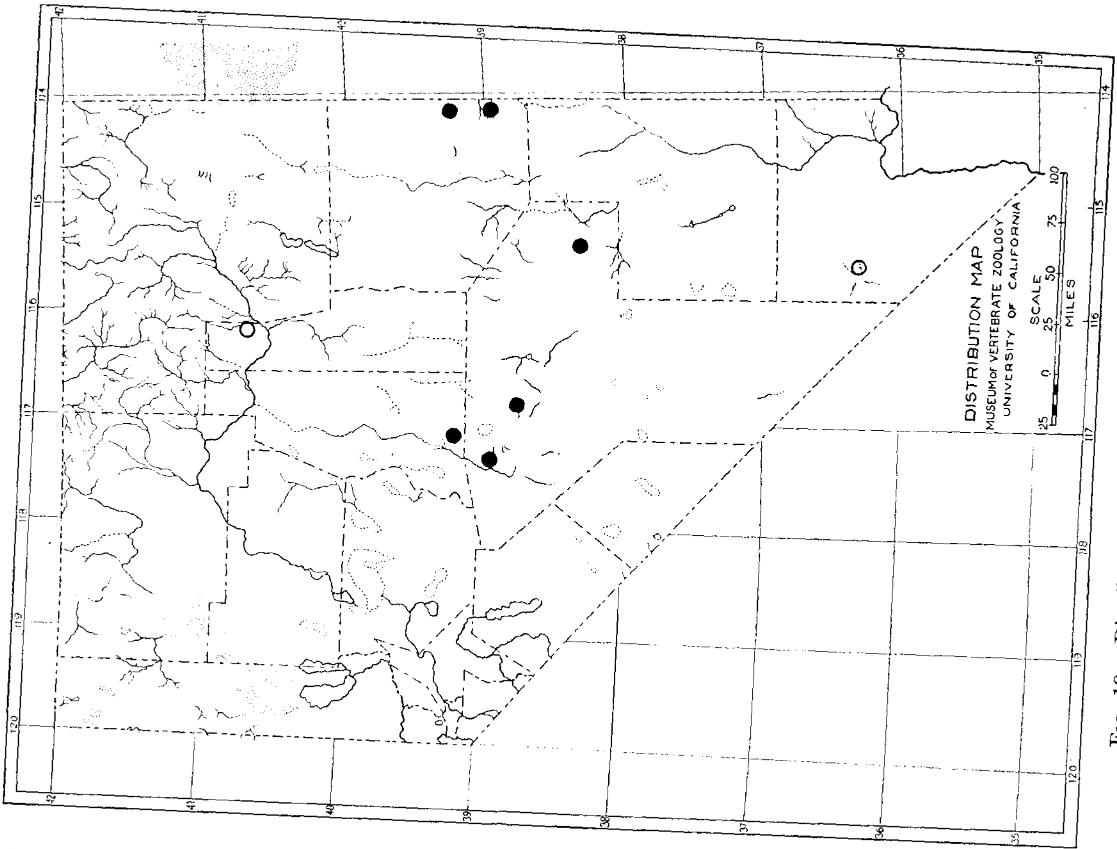
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FIG. 19. Distribution of *Eumeces skiltonianus* in Nevada.

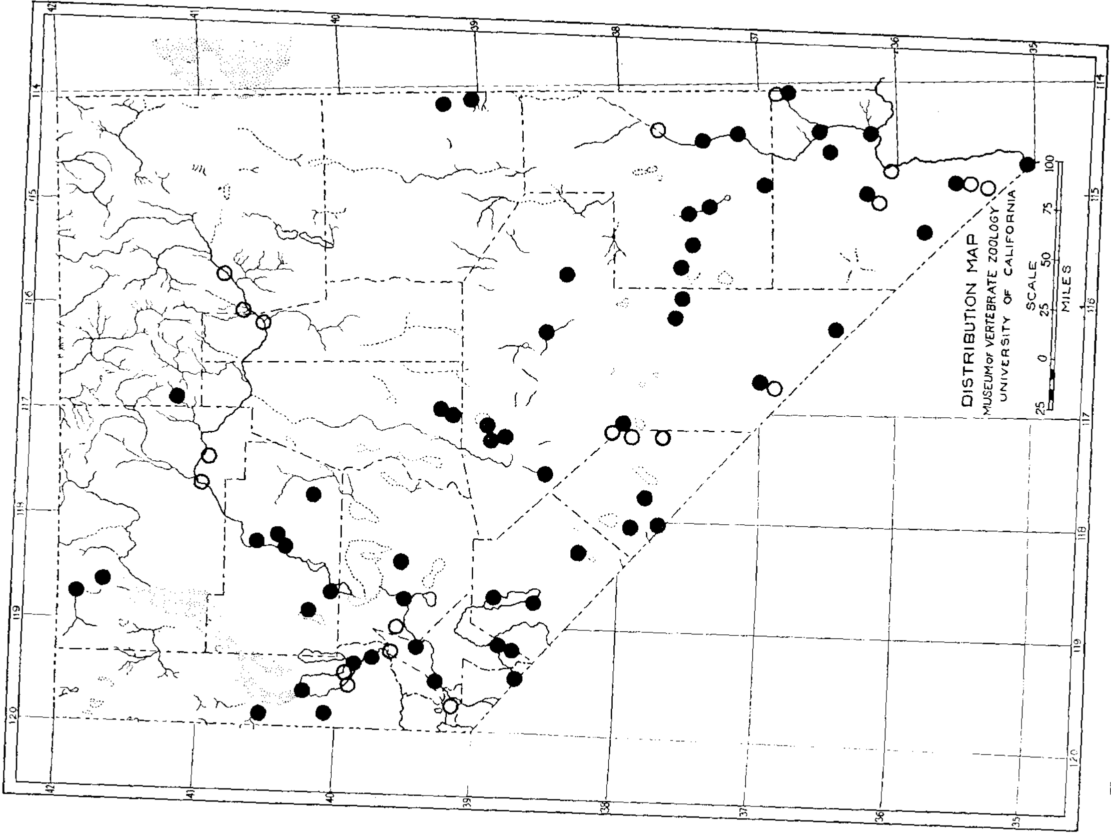
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FIG. 18. Distribution of *Cnemidophorus tesselatus tesselatus* in Nevada.

live in the valleys and flats throughout the state at altitudes up to at least 6,500 feet.

Nevada localities (Fig. 18) (419 specimens in Museum of Vertebrate Zoology).—

Washoe County: Smoke Creek (U. S. N. M.); Smoke Creek, 3,900 feet, 9 miles east of California line (Mus. Vert. Zool.); near Sand Pass (Mus. Vert. Zool.); Fox Cañon, south of Pahrum Peak (Mus. Vert. Zool.); Flanigan, 4,200 feet (Mus. Vert. Zool.); north end of Pyramid Lake (Mus. Vert. Zool.; U. S. N. M.); The Willows (Burt, 1931, p. 185); Pyramid Lake Indian Agency (Mus. Vert. Zool.; U. S. N. M.); Anaho Island (U. S. N. M.); Sutcliffe (U. S. N. M.); Nixon (U. S. N. M.); between Pyramid Lake and Reno (Acad. Nat. Sci. Phila.); Truckee River, 12 miles northwest of Wadsworth (Mus. Vert. Zool.); Wadsworth (U. S. N. M.).

Ormsby County: Carson City (U. S. N. M.).

Douglas County: Topaz Lake (Mus. Vert. Zool.).

Lyon County: 1 mile southeast of Fernley (Burt, 1933, p. 248); Lincoln Highway, 22 miles west of Fallon (Mus. Vert. Zool.); 6½ miles east of Dayton (Mus. Vert. Zool.); 12 miles south of Yerington, West Walker River (Mus. Vert. Zool.); Mason Valley, 12 miles east of Wellington (Mus. Vert. Zool.).

Humboldt County: Pine Forest Mountains (Mus. Vert. Zool.); Thousand Creek (Mus. Vert. Zool.); Big Creek Ranch (Mus. Vert. Zool.); Golconda (U. S. N. M.); Winnemucca (Burt, 1931, p. 185).

Elko County: Carlin (U. S. N. M.); Annie Creek (Univ. Mich.); Maggie Creek (Univ. Mich.); Elko (Burt, 1931, p. 185); 11 miles southwest of Midas (Mus. Vert. Zool.).

Pershing County: 21 miles west and 2 miles north of Lovelock, 4,000 feet (Mus. Vert. Zool.); Toulon, 3,900 feet (Mus. Vert. Zool.); 3¼ miles north northeast of Toulon (Mus. Vert. Zool.); 1 mile east of Oreana, 4,300 feet (Mus. Vert. Zool.); El Dorado Cañon, 6,000 feet, west base of Granite Peak, East Range (Mus. Vert. Zool.).

Churchill County: Hazen (Burt, 1931, p. 185); 5 miles north and 1½ miles southwest of Fallon (Mus. Vert. Zool.); 4 miles northwest of Fallon (Burt, 1933, p. 248); 4½ miles east of Stillwater, 4,000 feet (Mus. Vert. Zool.).

Lander County: Smoky Valley, between Birch and Kingston creeks (Mus. Vert. Zool.); Kingston Creek, 6,000 feet (Mus. Vert. Zool.).

Eureka County: Palisade (Burt, 1931, p. 185).

White Pine County: Baker (Mus. Vert. Zool.); near Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.).

Mineral County: 8 miles southeast of Schurz, 4,100 feet (Mus. Vert. Zool.); Cottonwood Creek, 7,000 feet, Mount Grant (Mus. Vert. Zool.); Endowment Mine (Mus. Vert. Zool.); Marietta (Mus. Vert. Zool.).

Esmeralda County: 15 miles south of Tonopah (Mus. Vert. Zool.); 7 miles north of Arlemont (Mus. Vert. Zool.); Arlemont (Mus. Vert. Zool.); Dyer (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.); Cave Spring (Mus. Vert. Zool.); Goldfield (Burt, 1931, p. 185).

Nye County: Wisconsin Creek, 6,000 feet (Mus. Vert. Zool.); Cloverdale Ranch (Mus. Vert. Zool.); South Twin River, 6,500 feet (Mus. Vert. Zool.); Smoky Valley, 2 miles south and 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); Tonopah (Burt, 1931, p. 185); 8 miles southeast of Tonopah (Mus. Vert. Zool.); Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.); Oasis Valley (U. S. N. M.); 3 miles northeast and 2 miles southeast of Fairbanks Spring (Mus. Vert. Zool.); Shoshone Point (U. S. N. M.); Rhyolite (Calif. Acad. Sci.); 2 miles south of Big Dry Lake, Kawich Valley (Mus. Vert. Zool.); 6 and 7½ miles east of Cliff Spring, 6,000 feet (Mus. Vert. Zool.); Hot Creek Valley, 5,900 feet (Mus. Vert. Zool.); Able Spring, 5,000 feet, Railroad Valley (Mus. Vert. Zool.).

Lincoln County: 14 miles north-northwest of Groom Baldy (Mus. Vert. Zool.); 16 miles east of Groom Baldy, 4,600 feet (Mus. Vert. Zool.); Crystal Spring (Mus. Vert. Zool.); Ash Spring (Mus. Vert. Zool.); Pahranagat Valley (U. S. N. M.); 2 miles south of Alamo (Mus. Vert. Zool.); Desert Valley (Van Denburgh, 1922, p. 512); Caliente (Van Denburgh, 1922, p. 512); Meadow Creek Valley (Van Denburgh, 1922, p. 512); 21 miles south of Caliente, 3,200 feet (Mus. Vert. Zool.); 6 miles northeast of Carp, 3,000 feet (Mus. Vert. Zool.); Coyote Spring, 2500 feet (Mus. Vert. Zool.).

Clark County: Mesquite (San Diego Soc. Nat. Hist.); Saint Thomas (U. S. N. M.); valley of Muddy River (Van Denburgh, 1922, p. 512); valley of Virgin River (Van Denburgh, 1922, p. 512); near mouth of Virgin River (Mus. Vert. Zool.); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.); 10 miles northeast of Las Vegas, 2,000 feet (Mus. Vert. Zool.); Las Vegas (Calif. Acad. Sci.); Vegas Valley (Van

Denburgh, 1922, p. 512); 1 mile west of Jean (Mus. Vert. Zool.); 6 and 13 miles north of Searchlight (Mus. Vert. Zool.); Searchlight (Klauber, 1932, p. 123); Piute Valley (Klauber, 1932, p. 123); Boulder City (Cowles and Bogert, 1936, p. 39); Hiko Spring, 2,000 feet (Mus. Vert. Zool.); 2 miles northwest of Fort Mojave, 500 feet (Mus. Vert. Zool.); 2 and 5 miles southeast of Overton, 1,300 feet (Mus. Vert. Zool.); Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); 3 miles south of Mesquite, 2,500 feet (Mus. Vert. Zool.).

At Las Vegas, Klauber (1932, p. 123) found this species in the mesquite sand-hummocks. He was impressed by the "peculiar jerky motion, with frequent pauses, that characterizes the progress of this lizard when undisturbed, as compared with its great speed when alarmed."

In Elko County, Ruthven and Gaige (1915, p. 26) found this lizard on the flats where sagebrush, salt bush, and rabbit brush grew. It was most abundant among the last type of plant where the growth was densest. When alarmed, they ran swiftly with tail elevated or dodged into a mammal burrow. Stomachs contained spiders and insects, mainly grasshoppers and beetles. One individual had eaten a recently hatched young one of the same species. Eggs were still carried in females collected as late as July 13, but they had been laid by August 8. The young one that had been eaten was found on August 14.

Near Crystal Spring, in Pahranagat Valley, Lincoln County, Fitch (MS) on May 20, 1932, observed whip-tailed lizards to be abundant in the thick grass close to the water of a creek as well as among the bushes farther up the bank. It was also abundant two miles east of there on the ridges and in washes.

SCINCIDAE

Eumeces skiltonianus skiltonianus

(Baird and Girard)

Western Skink

Original description.—*Plestiodon Skiltonianum* Baird and Girard, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 69 (Oregon).

Synonyms for Nevada.—*Plestiodon skiltonianus* Van Denburgh, 1922, p. 578.

Eumeces skiltonianus, Ruthven and Gaige, 1915, p. 26.

Range.—British Columbia to Lower California and east to Idaho and Utah.

Occurrence in Nevada.—Skinks have been collected on five mountain ranges, from the Cortez Mountains to the Charleston Mountains. Record stations are mainly at altitudes between 6,500 and 8,000 feet. The animals are not especially common in any of the localities; they spend so much time beneath cover and are so elusive as to be hard to capture.

Nevada localities (Fig. 19) (11 specimens in Museum of Vertebrate Zoology).—

Lander County: Kingston Creek, 7,000 feet, Toyabe Mountains (Mus. Vert. Zool.).

Eureka County: James Creek, Cortez Mountains (Univ. Mich. Mus.).

White Pine County: 2 miles west of Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.); Baker Creek, 6,300 feet, Snake Mountains (Mus. Vert. Zool.).

Nye County: Mohawk R. S., Toyabe Mountains (Mus. Vert. Zool.); 1 mile east of Jefferson, 7,600 feet, Toquima Mountains (Mus. Vert. Zool.); Scofield Cañon, 8,000 feet, Mount Grant (Mus. Vert. Zool.).

Clark County: Charleston Park (San Diego Soc. Nat. Hist.; Cowles and Bogert, 1936, p. 39).

Suborder Serpentes

BOIDAE

Charina bottae (Blainville)

Rubber Snake

Original description.—*Tortrix Bottae* Blainville, Nouv. Ann. Mus. Hist. Nat., vol. 4, 1835, pp. (57–58) 289–290, pl. 26, figs. 1, 1*a*, 1*b* (California [Monterey?]).

Synonyms for Nevada.—*Charina plumbea*, Yarrow 1883, p. 142.

Charina bottae bottae, Van Denburgh and Slevin, 1921, p. 36.

Range.—Washington south to San Bernardino Mountains, in California and east to Montana, Wyoming, and Utah.

Occurrence in Nevada.—The specimens known from the state are from localities close to or north of 39° N. Nine of them are from four mountain ranges as follows: Sierra Nevada; Santa Rosa Mountains; Jarbidge Mountains; Toyabe Mountains.

Nevada localities (Fig. 20) (7 specimens in Museum of Vertebrate Zoology).—

Washoe County: Big Bend of Truckee River (U. S. N. M.).

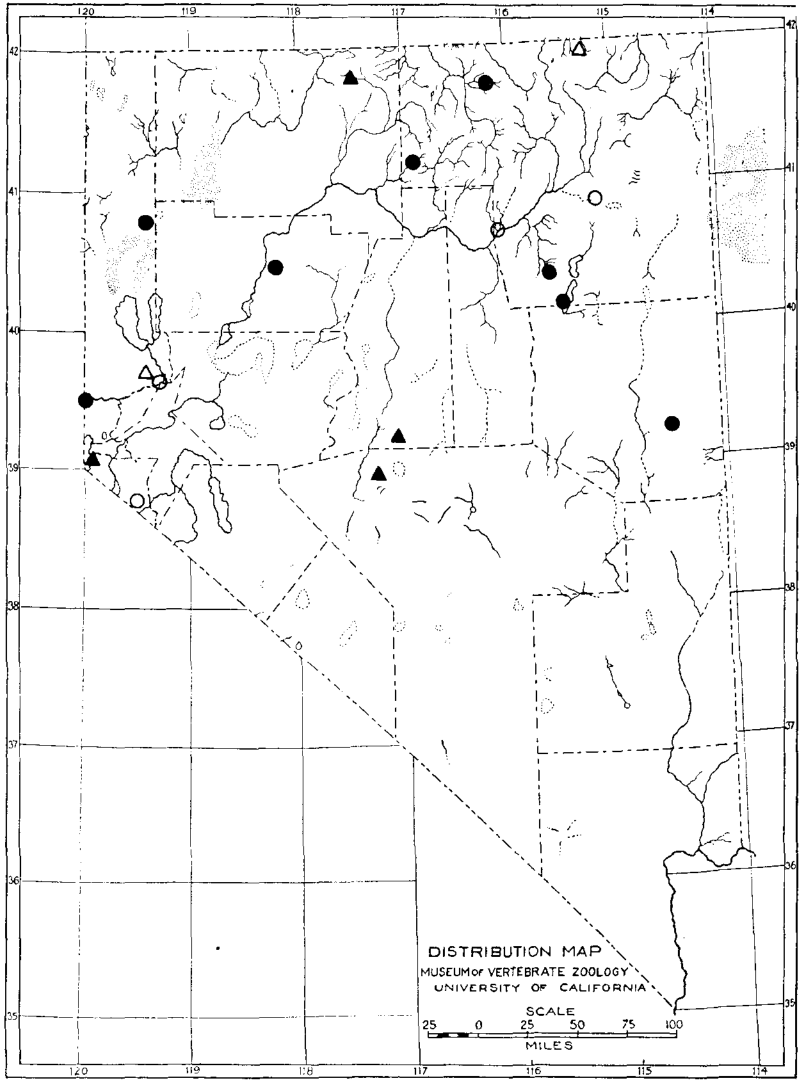
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FIG. 20. Distribution of *Charina bottae* (triangles) and *Coluber constrictor mormon* (circles) in Nevada.

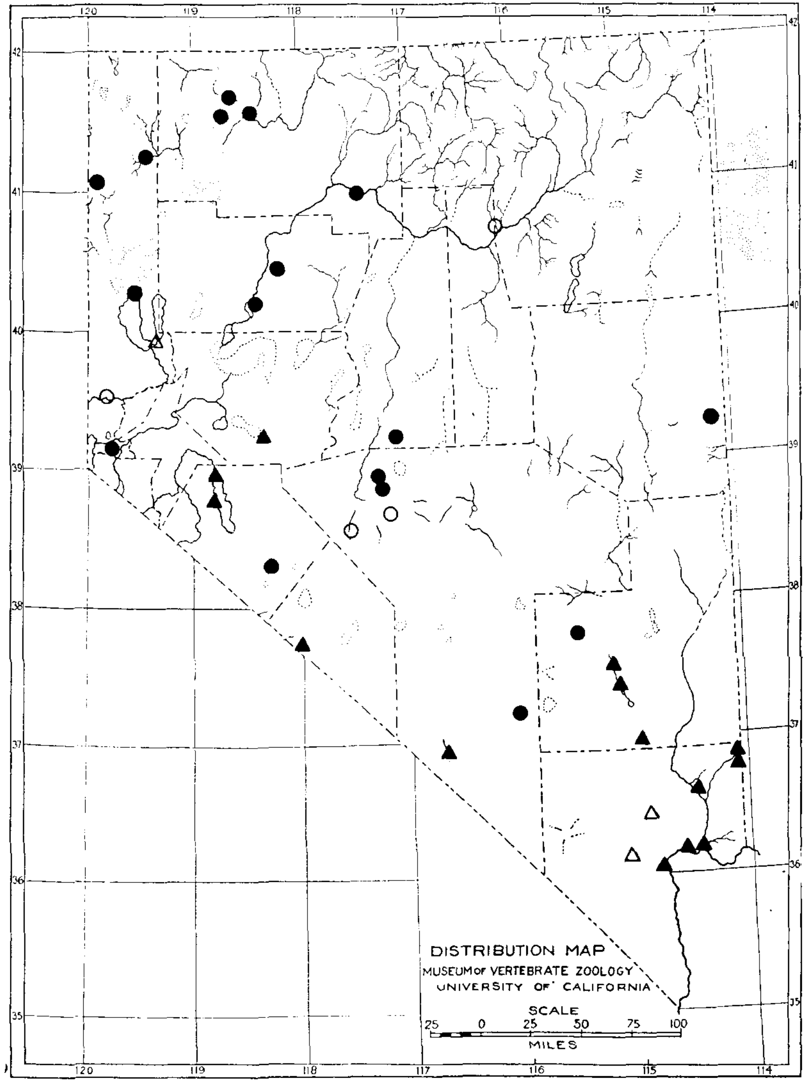
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FIG. 21. Distribution of *Coluber flagellum frenatum* (triangles) and *Coluber taeniatus taeniatus* (circles) in Nevada.

Ormsby County: no locality (U. S. N. M.).
Douglas County: Glenbrook (Mus. Vert. Zool.; Calif. Acad. Sci.).
Humboldt County: Martin Creek R. S., Santa Rosa Mountains (Mus. Vert. Zool.).
Elko County: 10 miles east of Jarbidge (U. S. N. M.).
Lander County: Kingston Creek, 6,400 and 7,000 feet, Toyabe Mountains (Mus. Vert. Zool.).
Nye County: Summit Creek, 6,800 feet, Toyabe Mountains (Mus. Vert. Zool.); Wisconsin Creek, 7,800 feet, Toyabe Mountains (Mus. Vert. Zool.).

COLUBRIDAE

Coluber constrictor mormon Baird and Girard

Yellow-bellied Racer

Original description.—*Coluber mormon* Baird and Girard, Stansbury's Expl. Surv. Vall. Great Salt Lake, Append. C, Rept., 1852, p. 351 (Valley of Great Salt Lake, Utah).

Synonym for Nevada.—*Bascanion constrictor vetustum,* Richardson, 1915, p. 427.

Range.—This race occurs along the Pacific coast from southern British Columbia to San Diego County, California, and eastward at least to the valley of Great Salt Lake, Utah.

Occurrence in Nevada.—Except for the Douglas County record, all Nevada specimens are from north of 39° N. They are mainly from valleys in the high plateau districts above 4,000 feet. The highest record stations are a little over 6,000 feet.

Nevada localities (Fig. 20) (12 specimens in Museum of Vertebrate Zoology).—

Washoe County: Rock Creek, 5,000 feet, Granite Mountains (Mus. Vert. Zool.); Wadsworth (Richardson, 1915, p. 427); Truckee River, 4,900 feet, near Verdi (Mus. Vert. Zool.).
Ormsby County: no locality given (U. S. N. M.).
Douglas County: Hornbrook [Holbrook] (Stan. Univ.).
Elko County: Humboldt River Valley (Univ. Mich. Mus.); Cortez Mountains (Univ. Mich. Mus.); Snell Cañon, Ruby Mountains (Calif. Acad. Sci.); Harrison Pass R. S. (Mus. Vert. Zool.); west side of Ruby Lake (Mus. Vert. Zool.); 5 miles southwest of Whiterock (Mus. Vert. Zool.); 11 miles southwest of Midas (Mus. Vert. Zool.).
Pershing County: El Dorado Cañon, 6,000 feet, West Humboldt Range (Mus. Vert. Zool.).
White Pine County: Cleveland Ranch, Spring Valley (Mus. Vert. Zool.).

Ruthven and Gaige (1915, p. 30) found a colony of yellow-bellied racers in Elko County, on a stony slope just beneath the northern peak of the Cortez Range. The snakes were very agile and rushed away to the shelter of rocks when alarmed.

Coluber flagellum frenatum (Stejneger)

Red Racer

Original description.—*Bascanion flagellum frenatum* Stejneger, North Amer. Fauna, no. 7, 1893, pp. 208–209 (Mountain Springs, Colorado Desert, San Diego County, California).

Synonyms for Nevada.—*Bascanion flagelliforme* subspecies *testaceum,* Yarrow, 1875, p. 542.
Bascanion flagellum frenatum, Richardson, 1915, p. 427.
Coluber flagellum piceus, Van Denburgh, 1922, p. 664.
Masticophis flagellum frenatus, Klauber, 1932, p. 124.

Range.—Southward from Mariposa County in California and southern Washoe County in Nevada through Lower California and to northern Sinaloa; eastward to southwestern Utah.

Occurrence in Nevada.—Nevada localities for this species are all in the southern part of the state, south of the 40th parallel. They are restricted further to levels under 5,000 feet. Specimens usually have come from the leveler parts of the valleys and deserts; evidently this snake avoids the steep slopes of mountains.

Nevada localities (Fig. 21) (15 specimens in Museum of Vertebrate Zoology).—

Washoe County: Winnemucca Lake (Van Denburgh, 1922, p. 670).
Churchill County: Sand Springs (Mus. Vert. Zool.).
Mineral County: Near Schurz (Mus. Vert. Zool.); west side of Walker Lake, 23½ miles northwest of Hawthorne (Mus. Vert. Zool.).
Esmeralda County: Fish Lake (Mus. Vert. Zool.).
Nye County: Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.).
Lincoln County: Crystal Spring (Mus. Vert. Zool.); 4 miles south of Alamo (Mus. Vert. Zool.); 1 mile west of Coyote Spring (Mus. Vert. Zool.).
Clark County: Mesquite (Mus. Vert. Zool.); 1 mile west of Bunkerville (Mus. Vert. Zool.);

Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); Overton (U. S. N. M.); Kaolin (Mus. Vert. Zool.); Vegas Valley (U. S. N. M.); Las Vegas (Van Denburgh, 1922, p. 670); Garnet (Klauber, 1932, p. 124); near mouth of Virgin River (Mus. Vert. Zool.); Colorado River, 3 and 20 miles above Boulder Dam (Mus. Vert. Zool.); vicinity of Boulder City (Cowles and Bogert, 1936, p. 39); Hiko Spring, 2,000 feet (Mus. Vert. Zool.); Colorado River, 6 miles north of California boundary (Mus. Vert. Zool.).

Three red racers were obtained toward the end of May, 1932, near Crystal Spring, Pahranagat Valley. The first one was found about 4 p. m. on May 24, in an *Atriplex* bush. It moved rapidly through the bush, keeping on the side opposite the collector (Fitch, MS) and finally coiled in the middle of the shrub, vibrating its tail and making a rattling sound among the dry leaves. When it was caught, the snake attempted to bite and it struggled violently with a rolling movement of the body in its effort to escape.

Coluber taeniatus taeniatus (Hallowell)

Striped Racer

Original description.—*Leptophis taeniata* Hallowell, Proc. Acad. Nat. Sci. Phila., vol. 6, 1852, p. 181 (New Mexico west of Rio Grande).

Synonyms for Nevada.—*Bascanium taeniatum* subspecies *laterale*, Yarrow, 1875, p. 543.

Bascanium taeniatum taeniatum, Yarrow, 1883, p. 112.

Bascanion taeniatum, Richardson, 1915, p. 428.

Range.—Idaho and Utah south to Mexico and from eastern margin of California and Oregon to western part of Texas.

Occurrence in Nevada.—Frequent in the valleys over most of the state, south at least to 37° 15′ N., in Nye County. Localities of capture are mostly between levels of 4,000 and 6,500 feet.

Nevada localities (Fig. 21) (24 specimens in Museum of Vertebrate Zoology).—

Washoe County: Little High Rock Cañon (Mus. Vert. Zool.); 8 1/8 miles southeast of Hausen, 4,800 feet (Mus. Vert. Zool.); Fox Cañon, 6 miles south of Pahrum Peak (Mus. Vert. Zool.); Pyramid Lake (U. S. N. M.); near Reno (Univ. Kans.).

Ormsby County: Carson City (U. S. N. M.); 4 miles southwest of Carson City (Mus. Vert. Zool.).

Humboldt County: Big Creek, 5,000 feet (Mus. Vert. Zool.); Leonard Creek, 4,700 feet (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); 5 miles southeast of Quinn River Crossing, 4,000 feet (Mus. Vert. Zool.); 6 miles east of Golconda (Mus. Vert. Zool.).

Elko County: Humboldt River Valley (Univ. Mich. Mus.); Annie Creek, Carlin (Univ. Mich. Mus.); Maggie Cañon (Univ. Mich. Mus.).

Pershing County: 5 miles east of Lovelock (Mus. Vert. Zool.); El Dorado Cañon, 6,000–8,000 feet, West Humboldt Range (Mus. Vert. Zool.).

Lander County: Kingston Creek, 6,000 feet (Mus. Vert. Zool.).

White Pine County: Antelope Springs (U. S. N. M.); near Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.).

Mineral County: Endowment Mine, Excelsior Mountains (Mus. Vert. Zool.).

Nye County: Wisconsin Creek, 6,000 feet (Mus. Vert. Zool.); North Twin River, 6,500 feet (Mus. Vert. Zool.); South Twin River, 6,500 feet (Mus. Vert. Zool.); Pablo Creek, 6,200 feet (U. S. N. M.); Cloverdale (U. S. N. M.); ½ mile south of Oak Spring, 5,700 feet (Mus. Vert. Zool.).

Lincoln County: North end of Timpahute Range, 5,300 feet (Mus. Vert. Zool.).

Taylor (1912, p. 353) captured four striped racers in the vicinity of the Pine Forest Mountains, Humboldt County. He observed that while these snakes did not move as rapidly as red racers, they were by no means sluggish. Two attempted to escape by climbing through a large sage bush. They fought vigorously, coiling themselves about the limbs of the bushes and resisting capture.

The stomach of one specimen obtained by Ruthven and Gaige (1915, p. 29) in Elko County, contained a whip-tailed lizard.

Fitch (MS) found a striped racer at the north end of Timpahute Range, 5,300 feet, on May 15, 1932. It was in a rocky outcrop in a small ravine, part of a coil protruding from beneath a flat rock.

Salvadora grahamiae hexalepis (Cope)

Patch-nosed Snake

Original description.—*Phimothyra hexalepis* Cope, Proc. Acad. Nat. Sci. Phila., 1866 (1867), p. 304 (Fort Whipple, Arizona).

Synonyms for Nevada.—*Salvadora hexalepis*, Van Denburgh and Slevin, 1921, p. 37.

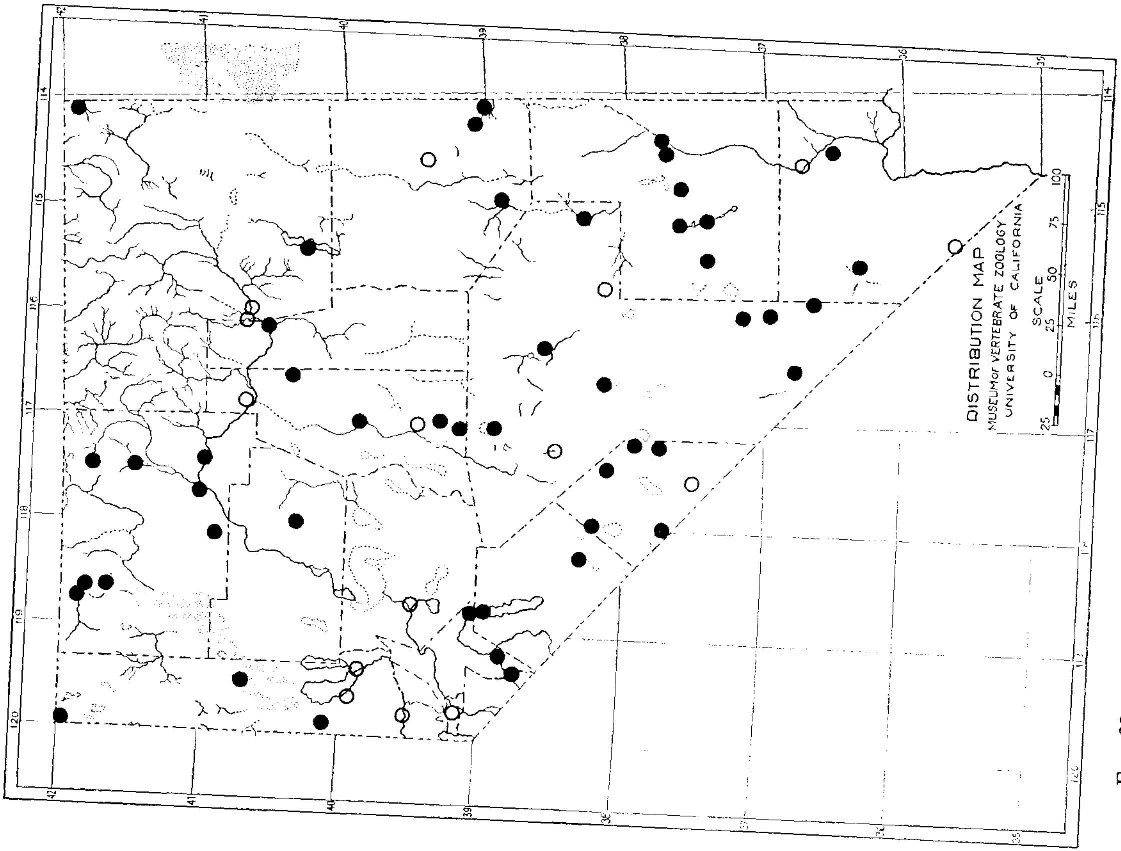
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FIG. 23. Distribution of *Pituophis catenifer deserticola* in Nevada.

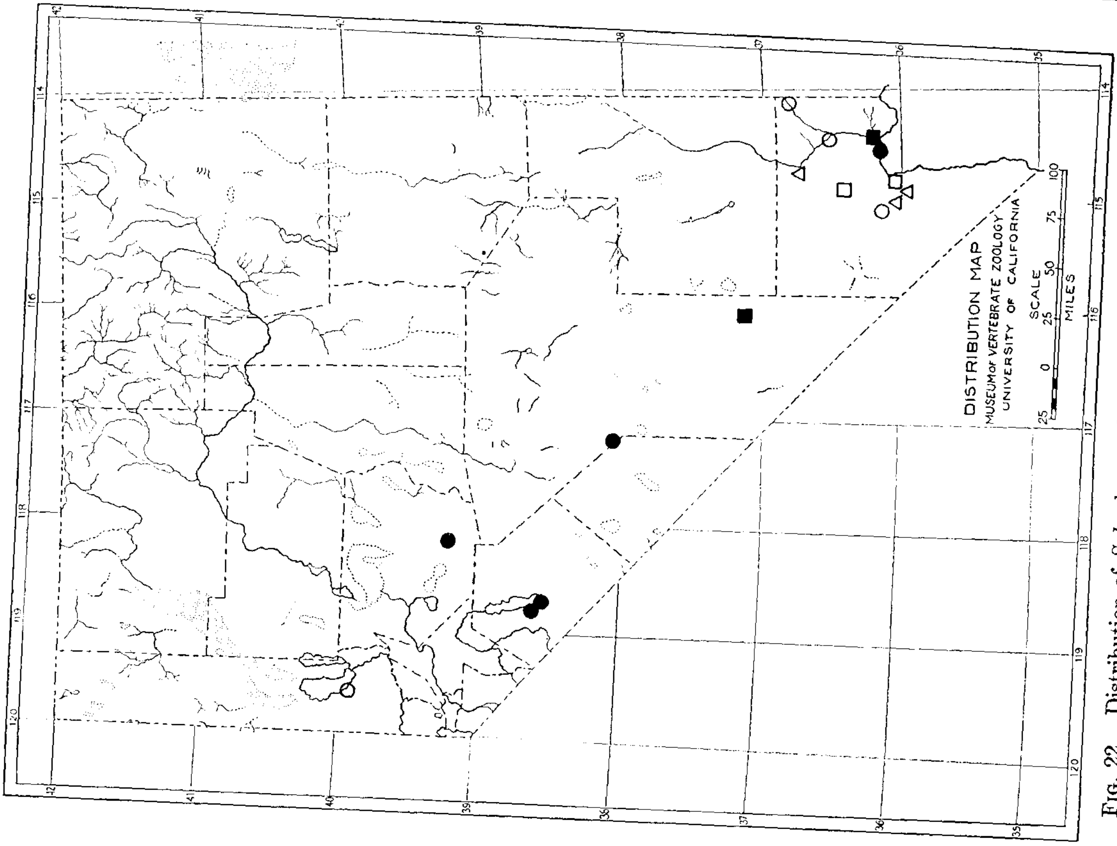
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FIG. 22. Distribution of *Salvadora grahamiae hexalepis* (circles), *Phyllorhynchus decurtatus perkinsi* (triangles), and *Arizona elegans occidentalis* (squares) in

Salvadora grahamiae, Van Denburgh, 1897, p. 182.

Range.—Desert regions of California, Nevada, Utah, Arizona, and western Mexico; also southern Lower California and Tiburon Island (as restricted by Bogert, 1935, p. 89).

Occurrence in Nevada.—The eight record stations are all south of the 40th parallel and they range in altitude from a little below 1,500 feet up to around 6,000 feet. Two specimens in the Museum of Vertebrate Zoology were picked up dead in roads.

Nevada localities (Fig. 22) (4 specimens in Museum of Vertebrate Zoology).—

Washoe County: Sutcliffe, Pyramid Lake (Calif. Acad. Sci.).

Churchill County: 7½ miles east of Frenchman's Station (Mus. Vert. Zool.).

Mineral County: Cottonwood Creek, Mount Grant (Mus. Vert. Zool.); west side of Walker Lake, 7½ miles northwest of Hawthorne (Mus. Vert. Zool.).

Nye County: Tonopah (Mus. Vert. Zool.).

Clark County: Virgin River, near Bunkerville (U. S. N. M.); near Saint Thomas (U. S. N. M.); Las Vegas (Van Denburgh, 1922, p. 691); Colorado River, 20 miles above Boulder Dam (Mus. Vert. Zool.).

Phyllorhynchus decurtatus perkinsi Klauber

Leaf-nosed Snake

Original description.—*Phyllorhynchus decurtatus perkinsi* Klauber, Bull. Zool. Soc. San Diego, no. 12, pp. 11–16 (Dry Lake, San Diego County, California).

Synonym for Nevada.—*Phyllorhynchus decurtatus*, Klauber, 1932, p. 125.

Range.—Southeastern California, southern Nevada and western Arizona.

Occurrence in Nevada.—So far recorded only from the vicinity of paved highways which cross Clark County. Klauber (1932, p. 125) reported that the specimen from near Glendale was found on a high, rocky mesa with sparse vegetation.

Nevada localities (Fig. 22) (No specimens in Museum of Vertebrate Zoology).—

Clark County: 10 and 15 miles southeast of Las Vegas (U. C. L. A.); 5 miles southwest of Glendale (Klauber coll.).

Arizona elegans occidentalis Blanchard

Faded Snake

Original description.—*Arizona elegans occidentalis* Blanchard, Occas. Papers Mus. Zool. Univ. Mich., no. 150, 1924, p. 1 (La Jolla, San Diego County, California).

Range.—Southern California and southern Nevada south to northern Lower California and southeastern Arizona.

Occurrence in Nevada.—Present in the southern end of the state north at least to 37° 15′ N. and as high as 4,400 feet. Other localities indicate presence as far south at least as Boulder City and as low as 1,000 feet.

Nevada localities (Fig. 22) (4 specimens in Museum of Vertebrate Zoology).—

Nye County: 9½ miles south of Oak Spring, 4,400 feet (Mus. Vert. Zool.).

Clark County: Garnet (Klauber, 1932, p. 125); near mouth of Virgin River (Mus. Vert. Zool.); Boulder City (Cowles and Bogert, 1936, p. 40).

Klauber (1932, p. 125) commented that in the specimens found by him at Garnet the ground color was light brown, the spots dark brown; the color seemed midway between the dark coastal specimens of California and the light individuals from the Colorado Desert.

The specimen from Nye County, was taken on May 26, 1931, half an hour before sunset, as it lay motionless on the ground beneath a desert shrub (Hall, MS).

Pituophis catenifer deserticola Stejneger

Gopher Snake

Original description.—*Pituophis catenifer deserticola* Stejneger, N. Amer. Fauna, no. 7, 1893, p. 206 (Great Basin and southwestern deserts [= east slope of Beaverdam Mountains, southwestern Utah]).

Synonym for Nevada.—*Pituophis sayi bellona*, Yarrow, 1883, p. 106.

Range.—Deserts of eastern California, Nevada, and Utah, south to northeastern Lower California.

Occurrence in Nevada.—The gopher snake is the most common and most generally distributed kind of snake in Nevada. Records are numerous at altitudes up to a little over 7,000 feet. They are most frequent in the valleys between 4,000 and 6,000 feet. Although most frequent in moist situations gopher snakes are sometimes found far out on the desert several miles from water.

Nevada localities (Fig. 23) (62 specimens in Museum of Vertebrate Zoology).—

Washoe County: 12-mile Creek, ½ mile east of California line, 5,300 feet (Mus. Vert. Zool.); Deephole (Mus. Vert. Zool.); 3 miles northwest of Flanigan, 4,200 feet (Mus. Vert. Zool.); Sutcliffe, Pyramid Lake (Calif. Acad. Sci.; U. S. N. M.); Nixon (Stanford Univ.); 3 miles east of Reno (Univ. Mich.); Truckee River (U. S. N. M.).

Ormsby County: Carson City (Stanford Univ.).

Lyon County: Wellington (Mus. Vert. Zool.); between Wellington and Yerington (Mus. Vert. Zool.); 10 miles northwest of Walker Lake (Mus. Vert. Zool.).

Humboldt County: Virgin Valley (Mus. Vert. Zool.); Thousand Creek Flat (Mus. Vert. Zool.); Big Creek (Mus. Vert. Zool.); Winnemucca (Mus. Vert. Zool.); 5 miles north of Paradise Valley (Mus. Vert. Zool.); Martin Creek R. S., Santa Rosa Mountains (Mus. Vert. Zool.); 7 miles northeast of Golconda (Mus. Vert. Zool.); 11 miles east and 1 mile north of Jungo, 4,200 feet (Mus. Vert. Zool.).

Elko County: Goose Creek, 2 miles west of Utah line (Mus. Vert. Zool.); 5 miles southwest of Whiterock (Mus. Vert. Zool.); James Cañon (Univ. Mich.); Maggie Cañon (Univ. Mich.); Moleen Cañon (Univ. Mich.); Carlin (Calif. Acad. Sci.); South Fork Humboldt River (U. S. N. M.); 8 miles northeast of Midas (Mus. Vert. Zool.); west side of Ruby Lake, 5 miles east of Harrison Pass (Mus. Vert. Zool.).

Pershing County: Fanning, 5,000 feet, West Humboldt Range (Mus. Vert. Zool.).

Churchill County: Fallon (Klauber coll.).

Lander County: 10 miles northeast of Battle Mountain (Univ. Mich.); 30 miles north of Austin (Mus. Vert. Zool.); Austin (Calif. Acad. Sci.); 10 and 15 miles northeast of Tenabo (Mus. Vert. Zool.); 2 miles north of Birch Creek Ranch, 6,000 feet (Mus. Vert. Zool.); Kingston Creek, 6,000 and 6,500 feet (Mus. Vert. Zool.).

Eureka County: 1 mile east of Palisade (Mus. Vert. Zool.).

White Pine County: Willard Creek, 7,150 feet, Spring Valley (Mus. Vert. Zool.); near Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.); Hendry Creek, 8 miles southeast of Mt. Moriah (Mus. Vert. Zool.); 5 miles northwest of Baker (Mus. Vert. Zool.); 3 miles southeast of Baker (Mus. Vert. Zool.); Water Cañon, 8 miles north of Lund (Mus. Vert. Zool.); Pyrmont (U. S. N. M.).

Mineral County: 3 miles south of Schurz (Mus. Vert. Zool.); Endowment Mine (Mus. Vert. Zool.).

Esmeralda County: 22 miles southeast of Mina (Mus. Vert. Zool.); Fish Lake (Mus. Vert. Zool.); Palmetto Mountains (Stanford Univ.); 13 miles south of Tonopah (Mus. Vert. Zool.); 2 miles north of Goldfield (Mus. Vert. Zool.).

Nye County: Peavine Creek (U. S. N. M.); Smoky Valley, 5 miles southeast of Millett P. O. (Mus. Vert. Zool.); Round Mountain (U. S. N. M.); 3 miles west of Miller's Wells (Mus. Vert. Zool.); 6 miles southeast of Carrara (Mus. Vert. Zool.); 2 miles southeast of Oak Spring, 5,500 feet (Mus. Vert. Zool.); 5 miles west of White Rock Spring, Belted Range (Mus. Vert. Zool.); 2 miles south of Yucca Pass, 3,500 feet (Mus. Vert. Zool.); White River Valley, 15 miles west-southwest of Sunnyside, 5,500 feet (Mus. Vert. Zool.); 6 miles south of Stone Cabin (Mus. Vert. Zool.); Hot Creek Valley, 6½ miles north of Hot Creek, 5,900 feet (Mus. Vert. Zool.); 19½ miles west of Indian Springs (Mus. Vert. Zool.).

Lincoln County: Hiko, 4,000 feet (Mus. Vert. Zool.); 10 miles west of Caliente (Mus. Vert. Zool.); 2 miles northwest of Caliente (Mus. Vert. Zool.); 20 miles east of Crystal Spring (Mus. Vert. Zool.); 12 miles southeast of Groom Baldy (Mus. Vert. Zool.); Alamo (Mus. Vert. Zool.).

Clark County: Glendale (Klauber, 1932, p. 125); 1 mile south of Roger's Spring, 2,000 feet, 10 miles south of Overton (Mus. Vert. Zool.); State-line Wells (Klauber, 1932, p. 125); 10 and 14½ miles east of Charleston Park (Mus. Vert. Zool.).

A gopher snake found by Richardson (1915, p. 427) coiled on a wood rat's nest at Pyramid Lake had eaten a ground squirrel (*Citellus mollis*). Another captured on July 9, near Carson City, contained large eggs.

All specimens obtained in Elko County, by Ruthven and Gaige (1915, p. 31) had eaten small mammals. A large female found on July 30 contained large eggs.

Lampropeltis getulus boylii (Baird and Girard)

King Snake

Original description.—*Ophibolus Boylii* Baird and Girard, Cat. N. A. Reptiles in Smiths. Inst., pt. 1, 1853, pp. 82–83 (Eldorado County, California).

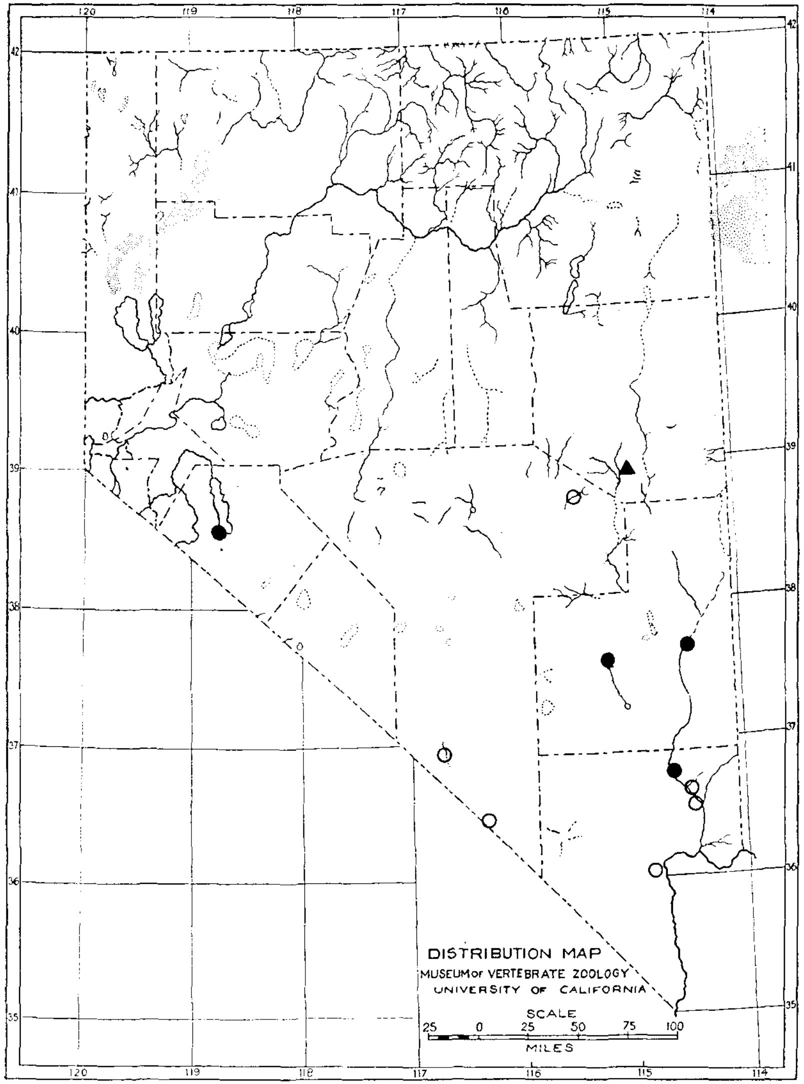
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FIG. 24. Distribution of *Lampropeltis getulus boylii* (circles) and *Lampropeltis pyromelana* (triangle) in Nevada.

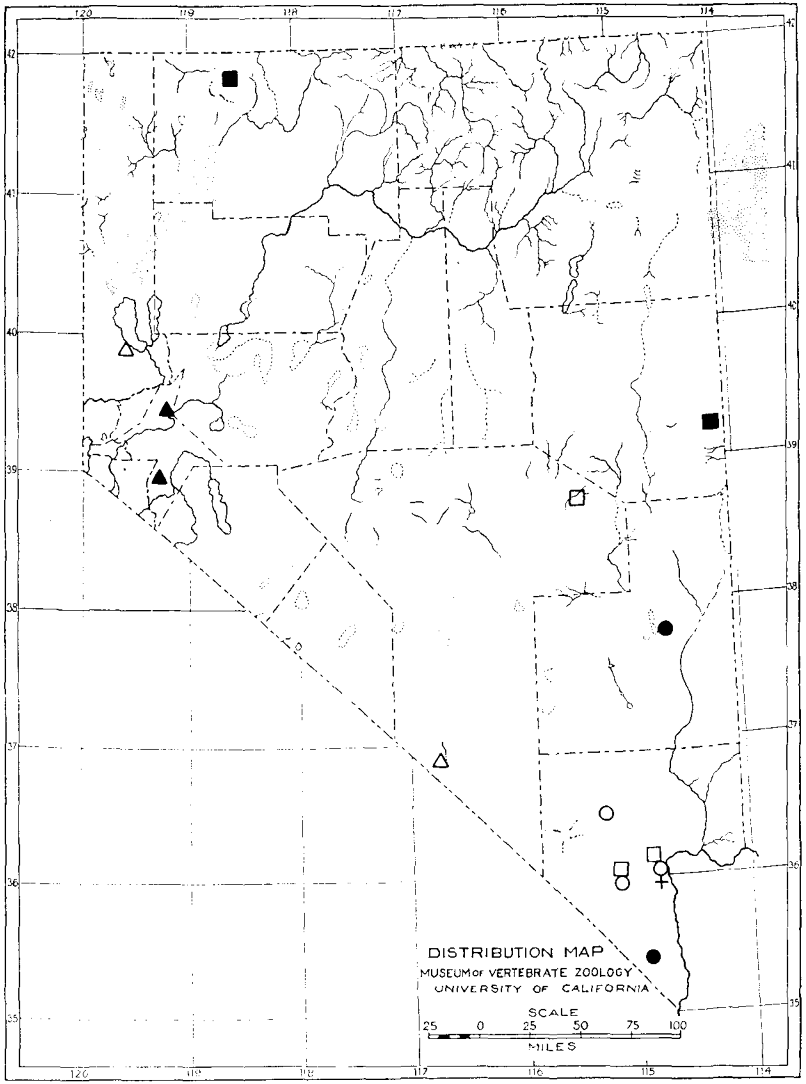
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FIG. 25. Distribution of *Rhinocheilus lecontei* (circles), *Hypsiglena ochrorhynchus ochrorhynchus* (squares), and *Sonora semiannulata* (triangles) and *Sonora occipitalis* (cross) in Nevada.

Synonyms for Nevada.—*Lampropeltis boylii,* Van Denburgh, 1897, p. 171.
Lampropeltis getulus californiae, Cowles and Bogert, 1936, p. 40.

Range.—This king snake has been captured at localities from Jackson County, Oregon south to Arizona and the San Joaquin Valley in California and east to southwestern Utah.

Occurrence in Nevada.—All records for this snake in Nevada are south of the 39th parallel. Three miles north of Crystal Spring, Pahranagat Valley, Lincoln County, an individual was caught at 5 p. m. on May 18, 1932, in grass at the margin of a lake (Anderson, MS).

Nevada localities (Fig. 24) (7 specimens in Museum of Vertebrate Zoology).—

Mineral County: near Walker Lake, 5.6 miles north of Hawthorne (Mus. Vert. Zool.).
Nye County: Amargosa River, 3½ miles northeast of Beatty (Mus. Vert. Zool.); Ash Meadows (Mus. Vert. Zool.); Currant (Van Denburgh, 1922, p. 755).
Lincoln County: 3 miles north of Crystal Spring (Mus. Vert. Zool.); Meadow Valley, 7 miles south of Caliente (Mus. Vert. Zool.).
Clark County: 1 mile north of Glendale (Mus. Vert. Zool.); Saint Thomas (U. S. N. M.); Overton (U. S. N. M.); Muddy Valley (Van Denburgh, 1922, p. 755); Boulder City (Cowles and Bogert, 1936, p. 40).

Lampropeltis pyromelana (Cope)

Arizona Ringed Snake

Original description.—*Ophibolus pyromelanus* Cope, Proc. Acad. Nat. Sci. Phila., 1866, p. 305 (Fort Whipple, Arizona).

Range.—From east-central Nevada and Utah east to southwestern New Mexico and south to northern Mexico.

Occurrence in Nevada.—So far as known the two specimens (nos. 14297–98, Mus. Vert. Zool.) from Water Cañon, White Pine County, are the first ones to be obtained in this state. This station, the northwesternmost for the species, is in the northeast part of White River Valley and is on the west side of the south end of Egan Range. It is about 2 miles south of 39° N. and is practically on the line of 115° W. This is approximately 20 miles south and a little west of the town of Ely.

Nevada locality (Fig. 24) (2 specimens in Museum of Vertebrate Zoology).—
White Pine County: Water Cañon, 8 miles north of Lund (Mus. Vert. Zool.).

The two snakes listed above were captured together at 8:30 a. m. on June 12, 1932, by L. M. Boyers (MS). They were in a crevice 3 inches wide and 18 inches long, about five feet from a juniper tree, and one of many cracks in a large outcrop of irregular, broken rocks on a steep southwest-facing slope and about 200 feet above the running water in the bottom of the cañon. The snakes were side by side, one partly on top of the other, with their heads inside the crevice. Apparently this was a mating pair.

Rhinocheilus lecontei Baird and Girard

Long-nosed Snake

Original description.—*Rhinocheilus Lecontei* Baird and Girard, Cat. N. A. Reptiles in Smiths. Inst., pt. 1, 1853, pp. 120–121 (San Diego, California).

Range.—This wide-ranging western species has been recorded from northern California and southern Idaho east to western Kansas south into northwestern Mexico and through Lower California.

Occurrence in Nevada.—The five specimens so far collected are from the southeastern part of the state: one locality is a few miles south of 38° N.; the other two close to 36° N. All are within 15 miles of 115° W. The northern one was taken in late afternoon on May 28, 1932, the others in April. At the Lincoln County locality the soil was gravelly and "white sage" the most abundant plant. The snake was found beneath a small desert shrub (Harville, MS).

Nevada localities (Fig. 25) (3 specimens in Museum of Vertebrate Zoology).—

Lincoln County: Desert Valley, 5,400 feet, 20 miles southwest of Pioche (Mus. Vert. Zool.).
Clark County: 15½ miles southeast of Indian Springs (Mus. Vert. Zool.); Sloan (Klauber, 1932, p. 126); Boulder City (Klauber, 1932, p. 126); 3½ miles south of Searchlight (Mus. Vert. Zool.).

Both specimens collected by Klauber (1932, p. 126) had considerable red or pink in the interspaces between the black blotches.

Hypsiglena ochrorhynchus ochrorhynchus Cope

Spotted Night Snake

Original description.—*Hypsiglena ochrorhynchus* Cope, Proc. Acad. Nat. Sci. Phila., 1860, pp. 246–247 (Cape San Lucas, [Lower] California).

Synonym for Nevada.—*Hypsiglena ochrorhynchus*, Klauber, 1932, p. 126.

Range.—Has been captured along the Pacific coast from the San Francisco Bay region California south to the cape district of Lower California. Eastward specimens come from Nevada, Utah and Arizona and Sonora, Mexico.

Occurrence in Nevada.—Recorded from four widely scattered localities, indicating scattered distribution throughout the state. The specimen from Sloan was found crushed on the highway. It had swallowed a lizard (Klauber, 1932, p. 126).

Nevada localities (Fig. 25) (2 specimens in Museum of Vertebrate Zoology.)—

Humboldt County: Virgin Valley (Mus. Vert. Zool.).
White Pine County: 2 miles west of Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.).
Nye County: Currant (Van Denburgh, 1922, p. 783).
Clark County: Sloan (Klauber, 1932, p. 126); 4 miles west of Boulder City (Cowles and Bogert, 1936, p. 41).

Sonora occipitalis (Hallowell)

Burrowing Snake

Original description.—*Rhinostoma occipitale* Hallowell, Proc. Acad. Nat. Sci. Phila., vol. 7, 1854, p. 95 (Mohave Desert, California).

Range.—Southeastern California and Arizona, and southern Nevada.

Occurrence in Nevada.—The single specimen from Boulder City, listed below, was found beneath an incinerator in a yard.

Nevada locality (Fig. 25) (No specimen in Museum of Vertebrate Zoology).—

Clark County: Boulder City (Cowles and Bogert, 1936, p. 40).

Sonora semiannulata Baird and Girard

Burrowing Snake

Original description.—*Sonora semiannulata* Baird and Girard, Cat. N. Amer. Rept., pt. 1, 1853, p. 117 (Sonora, Mexico).

Synonyms for Nevada.—*Chionactis isozonus*, Richardson, 1915, p. 426.
Contia isozona, Yarrow, 1875, p. 537.

Range.—From Idaho and western Nevada eastward to about the 97th meridian in Kansas, Oklahoma, and Texas and south into Mexico.

Occurrence in Nevada.—One specimen was obtained at each of the four localities listed below. These localities are all in the desert area near the western border of the state. The snake from Pyramid Lake was found, about June 1, 1911, beneath a rock on a rise above the southwest shore of the lake (Richardson, 1915, p. 426). The one from Ludwig, Lyon County, was picked up dead in April, 1935, in a mine shaft (A. Casting, in letter). The Rhyolite specimen was found in early August, 1913, crawling over the surface of the desert just before dark (Van Denburgh and Slevin, 1921, p. 38). These and other records for the species indicate a preference for a rocky habitat.

A burrowing snake (no. 84908, Univ. Mich.) collected on August 1, 1938, by C. L. Hubbs in Pershing County, was assigned by Stickel (1938, p. 189) to the form *Sonora miniata linearis* newly described by him.

Nevada localities (Fig. 25) (2 specimens in Museum of Vertebrate Zoology).—

Washoe County: Pyramid Lake (Stan. Univ.).
Lyon County: Ludwig Gypsum Camp, 16 miles from Yerington (Mus. Vert. Zool.); Lincoln Highway, 22 miles west of Fallon (Mus. Vert. Zool.).
Nye County: Rhyolite (Calif. Acad. Sci.).

Thamnophis ordinoides couchii (Kennicott)

Garter Snake

Original description.—*Eutaenia couchii* Kennicott, *in* Baird, Pac. R. R. Rep., vol. 10, 1859, Abbot's Rep., pt. 4, no. 4, pp. 10–11 (Pit River, California).

Range.—Northeastern California and western Nevada south to Kern County, California.

Occurrence in Nevada.—Known from a few localities in central-western part of the state from Pyramid Lake to West Walker River, and east to Fallon.

Nevada localities (Fig. 26) (2 specimens in Museum of Vertebrate Zoology).—

Washoe County: Pyramid Lake (Stan. Univ.); Wadsworth (Stan. Univ.); Camp 12 (= Truckee River, near Wadsworth) (U. S. N. M.);

Truckee River, 4,900 feet, near Verdi (Mus. Vert. Zool.).
Douglas County: Glenbrook (Calif. Acad. Sci.).
Lyon County: West Walker River, 4,500 feet, 10½ miles south of Yerington (Mus. Vert. Zool.).
Churchill County: Fallon (U. S. N. M.).

Thamnophis ordinoides elegans (Baird and Girard)

Garter Snake

Original description.—*Eutainia elegans* Baird and Girard, Cat. N. Amer. Reptiles in Smiths. Inst., pt. 1, 1853, pp. 34–35 (Eldorado County, California).

Synonym for Nevada.—*Eutaenia elegans*, Yarrow and Henshaw, 1878, p. 1638.

Range.—Central Oregon and North Coast Ranges of California east to Warner Mountains and Sierra Nevada of Nevada and California and south through San Bernardino Mountains, California.

Occurrence in Nevada.—Localities for this garter snake are all near the central-western border of the state, between Reno and Minden and in or close to the Sierra Nevada. They range in altitude from 4,500 to 6,500 feet. All captures were made close to water.

Nevada localities (Fig. 26) (10 specimens in Museum of Vertebrate Zoology).—

Washoe County: Truckee River, 4,900 feet, near Verdi (Mus. Vert. Zool.); 8 miles southeast of Reno (Mus. Vert. Zool.); Tahoe Meadows, 8,500 feet (Mus. Vert. Zool.).
Douglas County: Glenbrook (Calif. Acad. Sci.); Minden, Carson River (Mus. Vert. Zool.); State-line, at southeast border of Lake Tahoe (Mus. Vert. Zool.).

Thamnophis ordinoides vagrans (Baird and Girard)

Garter Snake

Original description.—*Eutainia vagrans* Baird and Girard, Cat. N. Amer. Reptiles in Smiths. Inst., pt. 1, 1853, p. 35 (California).

Synonyms for Nevada.—*Thamnophis ordinoides elegans*, Richardson, 1915, p. 429.
Eutaenia vagrans vagrans, Yarrow, 1883, p. 119.
Thamnophis vagrans, Van Denburgh, 1897, p. 211.

Range.—Eastern Washington and Oregon, and Idaho, south to Arizona and from eastern California through Nevada and Utah to Alberta, South Dakota, and Oklahoma.

Occurrence in Nevada.—This Great Basin race of garter snake occurs over most of the state, south as far as Ash Meadows and as low as 2,200 feet. It is closely restricted to the near vicinity of water—in streams, lakes and ponds, and it ranges upward in the mountains at least to 8,500 feet.

Nevada localities (Fig. 26) (102 specimens in Museum of Vertebrate Zoology).—

Washoe County: Fish Creek (Univ. Mich.); Wall Cañon (Univ. Mich.); Grass Valley Creek (Univ. Mich.); Lost Creek (Univ. Mich.); Horse Cañon Spring (Univ. Mich.); Smoke Creek, 3,900 feet (Mus. Vert. Zool.); 4 miles southwest of Diessner, 5,800 feet (Mus. Vert. Zool.); Little High Rock Creek (Mus. Vert. Zool.); Pyramid Lake (U. S. N. M.); Winnemucca Lake (Van Denburgh, 1922, p. 833); Camp 12 (= Truckee River, near Wadsworth) (U. S. N. M.).
Humboldt County: Pine Forest Mountains (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); Virgin Valley (Mus. Vert. Zool.); Thousand Creek Flat (Mus. Vert. Zool.); 30 miles southwest of Denio (Univ. Mich.); spring at edge of Black Rock Desert (Univ. Mich.).
Elko County: Jerry Creek, Ruby Mountains (Mus. Vert. Zool.); Copper and Coon creeks (Mus. Vert. Zool.); Goose Creek (Mus. Vert. Zool.); Marys River, 23 miles north of Deeth (Mus. Vert. Zool.); Deeth (U. S. N. M.); 3 miles south of Halleck (U. S. N. M.); Elko (Calif. Acad. Sci.); Maggie Creek (Univ. Mich.); Moleen Cañon (Univ. Mich.); Ruby Lake (U. S. N. M.; Univ. Mich.); west side of Ruby Lake (Mus. Vert. Zool.); Cave Creek, Ruby Valley (Univ. Mich.); summit of Secret Pass, 6,200 feet (Mus. Vert. Zool.); Harrison Pass R. S. (Mus. Vert. Zool.); south fork of Long Creek (Mus. Vert. Zool.); Kleckner Creek (Mus. Vert. Zool.); Spring Creek (Univ. Mich.); Butte Creek (Univ. Mich.); Clover Valley (Univ. Mich.); Newark Valley (Univ. Mich.).
Churchill County: Fallon (U. S. N. M.).
Lander County: Battle Mountain (U. S. N. M.); Silver Creek (U. S. N. M.); Reese River Valley, 7 miles north of Austin (Mus. Vert. Zool.); Big Creek, Toyabe Mountains (Mus. Vert. Zool.); Kingston R. S., 7,500 feet (Mus. Vert. Zool.); Kingston Creek, 7,000 feet (Mus. Vert. Zool.).

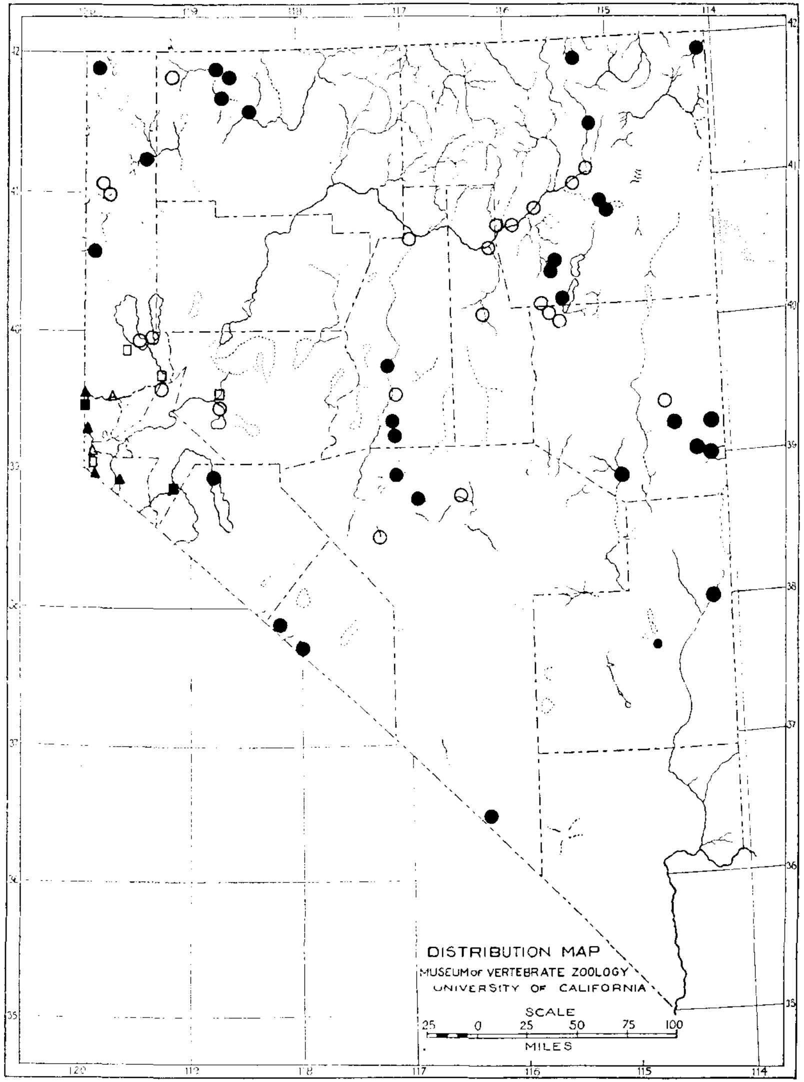
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FIG. 26. Distribution of *Thamnophis ordinoides vagrans* (circles), *Thamnophis ordinoides elegans* (triangles) and *Thamnophis ordinoides couchii* (squares) in Nevada.

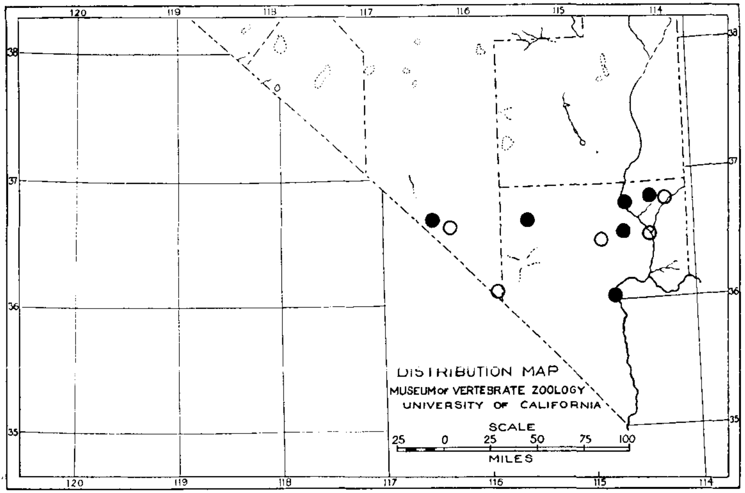
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FIG. 27. Distribution of *Crotalus cerastes* in southern Nevada.

Eureka County: Palisade (Van Denburgh, 1922, p. 833); Wenzell (Mus. Vert. Zool.).

White Pine County: Summit of Overland Pass (Mus. Vert. Zool.); Willow Creek, 2 miles south of county line (Mus. Vert. Zool.); Piermont (U. S. N. M.); Cleveland Ranch, 6100 feet, Spring Valley (Mus. Vert. Zool.); Smith Creek, 7,100 feet, Mt. Moriah (Mus. Vert. Zool.); Hendry Creek, 7,800 feet, Mt. Moriah (Mus. Vert. Zool.); Snake Valley (U. S. N. M.); Willard Creek, 7,150 feet (Mus. Vert. Zool.); Baker Creek, 6,600, 7,200, and 8,400 feet (Mus. Vert. Zool.); Water Cañon, 8 miles north of Lund (Mus. Vert. Zool.); White River (Univ. Mich.).

Mineral County: 3 miles south of Schurz (Mus. Vert. Zool.).

Esmeralda County: Chiatovich Creek, 8,200 feet (Mus. Vert. Zool.); Fish Lake, 4,800 feet (Mus. Vert. Zool.).

Nye County: Smoky Valley (Calif. Acad. Sci.); Millett P. O., 5,500 feet (Mus. Vert. Zool.); 5 miles southeast of Millett P. O. (Mus. Vert. Zool.; Univ. Mich.); Peavine Creek, 6,600 feet, Toyabe Mountains (U. S. N. M.); 1 mile east of Jefferson, 7,600 feet (Mus. Vert. Zool.); Greenmonster Cañon, 8,200 feet, Monitor Mountains (Mus. Vert. Zool.); Ash Meadows (U. S. N. M.); Ballinger Ranch, Ash Meadows (Mus. Vert. Zool.).

Lincoln County: 3½ miles north of Eagle Valley, 5,600 feet (Mus. Vert. Zool.).

In the grassy marshes along the Quinn River this garter snake was fairly common in 1909 (Taylor, 1912, p. 355). When pursued they moved rapidly and took refuge in water, in some irrigation ditch or in a pool in the river. Tadpoles were disgorged by some individuals. One, found crawling over a nest of white-crowned sparrows, was thought to be after the young birds. A female captured on July 31, at 8,400 feet, contained eggs nearly ready for hatching.

Specimens obtained at Elko in mid-July, had been eating larvae of *Rana pipiens* (Van Denburgh and Slevin, 1921, p. 38).

Ruthven and Gaige (1915, p. 32) found this garter snake to be common along the larger permanent streams in western Elko County. They considered that most of its food came from the water; one had eaten a toad, others contained fish and tadpoles. Three females gave birth to eight, ten, and twelve young on August 25, September 2, and September 10. Richardson (1915, p. 433) reported the capture in the Lahontan basin of females containing large eggs as follows: Pyramid Lake Indian Agency, late May; Palisade, Eureka County, two on July 3 and 4. He concluded that in this area in June and July the chief food of this snake was small minnows.

Thamnophis sirtalis infernalis (Blainville)

Garter Snake

Original description.—*Coluber infernalis* Blainville, Nouv. Ann. Mus. Nat. Hist., vol. 4, 1835, pp. [59–60] 291–292, pl. 26, figs. 3–3*a* (California).

Synonyms for Nevada.—*Eutaenia sirtalis sirtalis*, Yarrow, 1883, p. 123.

Eutaenia sirtalis parietalis, Yarrow, 1883, p. 125.

Eutaenia sirtalis obscura, Yarrow, 1883, p. 126.

Thamnophis sirtalis parietalis, Richardson, 1915, p. 428.

Range.—From southern Oregon to northern San Diego County, California (except northwest coastal area) and east to western Nevada.

Occurrence in Nevada.—So far known only from near the central-western border of the state—near the south end of Pyramid Lake and close to the Carson River in Douglas County.

Nevada localities (2 specimens in Museum of Vertebrate Zoology).—

Washoe County: Nixon (Van Denburgh, 1922, p. 806); Camp 12 (= Truckee River, near Wadsworth) (U. S. N. M.).

Douglas County: 2 miles north of Minden (Mus. Vert. Zool.); Carson River near Minden (Mus. Vert. Zool.); Carson Valley (U. S. N. M.).

Trimorphodon vandenburghi Klauber

Lyre Snake

Original description.—*Trimorphodon vandenburghi* Klauber, Bull. Zool. Soc. San Diego, no. 1, 1924, p. 17 (Wildwood Ranch, 1,520 feet, near Ramona, San Diego County, California).

Range.—Southern California and southern Nevada.

Occurrence in Nevada.—The single specimen from Nevada was sent to L. M. Klauber. It was found in the substation of the Southern Sierra Power Company, near Boulder Dam.

Nevada locality (No specimen in Museum of Vertebrate Zoology).—

Clark County: near Boulder Dam (Klauber coll.).

CROTALIDAE

Crotalus atrox Baird and Girard

Rattlesnake

Original description.—*Crotalus atrox* Baird and Girard, Cat. N. A. Reptiles in Smiths. Inst., pt. 1, 1853, pp. 5–6 (Indianola or San Pedro, Texas).

Synonym for Nevada.—*Crotalus cinereous*, Klauber, 1936, p. 239. This is now (Jan. 1, 1940) the accepted name for this snake.

Range.—From the Colorado Desert east to western Arkansas and the Trinity River in Texas and south into Mexico.

Occurrence in Nevada.—Known from only one locality in the state, on the plain of the Colorado River in the extreme southern tip of Clark County. Specimens were captured there on May 7 and 10, 1934, and April 22, 1936.

Nevada locality (4 specimens in Museum of Vertebrate Zoology).—

Clark County: Colorado River, opposite Fort Mojave (Mus. Vert. Zool.).

Crotalus cerastes Hallowell

Sidewinder

Original description.—*Crotalus cerastes* Hallowell, Proc. Acad. Nat. Sci. Phila., vol. 7, 1854, pp. 95–96 (Mohave Desert, California).

Range.—The deserts of southeastern California, southern Nevada, southwestern Utah, western Arizona, northwestern Sonora, and northeastern Lower California.

Occurrence in Nevada.—Frequent in the sandy deserts of Nye and Clark counties, south of 37° N. Localities extend up to 4,500 feet.

Nevada localities (Fig. 27) (6 specimens in Museum of Vertebrate Zoology).—

Nye County: Amargosa Desert (U. S. N. M.); North Amargosa, 4,500 feet (U. S. N. M.); 18 miles southeast of Beatty (Mus. Vert. Zool.); 15 miles north of Ash Meadows (U. S. N. M.); Pahrump Valley (U. S. N. M.).

Clark County: 2 miles west of Indian Springs (Mus. Vert. Zool.); Indian Spring Valley (U. S. N. M.); 1 mile north of Glendale (Mus. Vert. Zool.); Glendale (Klauber, 1932, p. 128); Mormon Mesa, 2,000 feet, 14 miles east of Glendale (Mus. Vert. Zool.); Mormon Mesa, near Virgin River (Klauber, 1932, p. 128); Dry Lake (Klauber, 1932, p. 128); Atlatl Rock, 2,000 feet, Valley of Fire (Mus. Vert. Zool.); 1 mile south of Saint Thomas (Mus. Vert. Zool.); Cottonwood Cañon (Yarrow, 1883, p. 73); Colorado River, 3 miles above Boulder Dam (Mus. Vert. Zool.); near Boulder City (Cowles and Bogert, 1936, p. 41).

Crotalus confluentus lutosus Klauber

Rattlesnake

Original description.—*Crotalus confluentus lutosus* Klauber, Trans. San Diego Soc. Nat. Hist., vol. 6, no. 3, 1930, p. 100, pl. 10, fig. 1 (10 miles northwest of Abraham on the road to Joy, Millard County, Utah).

Synonyms for Nevada.—*Crotalus confluentus*, Yarrow, 1883, p. 77.
Crotalus lucifer, Ruthven and Gaige, 1915, p. 33.
Crotalus oregonus, Richardson, 1915, p. 433.
Crotalus oreganus, Van Denburgh, 1921, p. 38.
Crotalus viridis lutosus, Klauber, 1936, p. 242. This is now (Jan. 1, 1940) the accepted name for this snake.

Range.—Southeastern Oregon and northern California, east of Sierra Nevada, east to 111th meridian in Utah and south in Utah and Nevada to the edge of the high plateau of the Great Basin.

Occurrence in Nevada.—Widespread over most of the plateau in the northern part of the state, south to about 38° N. in the west and 37° in the east side. Inhabits mainly the floors of the valleys; especially frequent about alfalfa fields. Also present, but less frequent, in the mountains. Found mostly at altitudes between 4,000 and 7,000 feet. Dates of capture of specimens in Museum of Vertebrate Zoology range from May 11 to September 9, and they probably represent the normal seasonal limits of activity.

Nevada localities (Fig. 28) (90 specimens in Museum of Vertebrate Zoology).—

Washoe County: 12-mile Creek, ½ mile east of California line, 5,300 feet (Mus. Vert. Zool.); Painted Point, 6,000 feet, 9 miles east of Vya (Mus. Vert. Zool.); 14½ miles north and 3½ miles east of Vya, 5,900 feet (Mus. Vert. Zool.); 2½ miles east and 11 miles north of Gerlach, 4,050 feet (Mus. Vert. Zool.); 3½ miles west of Flanigan, 4,200 feet (Mus. Vert. Zool.); Horse Cañon, 6,000 feet, Pahrum Peak (Mus. Vert. Zool.); Fox Cañon, 6 miles south of Pahrum Peak (Mus. Vert. Zool.); Pyramid Lake (U. S. N. M.); 18 miles northeast of Reno (Mus. Vert. Zool.); Truckee River (U.S.N.M.); Truckee River, 12 miles northwest of Wadsworth (Mus. Vert. Zool.).

Lyon County: 6 miles north of Fernley (Mus. Vert. Zool.); West Walker River, 12 miles south of Yerington (Mus. Vert. Zool.).

Humboldt County: Virgin Valley (Mus. Vert. Zool.); Big Creek (Mus. Vert. Zool.); near Big Creek Ranch (Mus. Vert. Zool.); Leonard Creek (Mus. Vert. Zool.); Quinn River Crossing (Mus. Vert. Zool.); Martin Creek R. S. (Mus. Vert. Zool.); 26 miles northwest of Battle Mountain (Mus. Vert. Zool.).

Elko County: Mountain City (U. S. N. M.); 8 miles south of Mountain City (Mus. Vert. Zool.); Cedar Creek, 5,600 feet, 9 miles northeast of San Jacinto (Mus. Vert. Zool.); 11 miles southwest of Midas (Mus. Vert. Zool.); Cortez Mountains (Univ. Mich.); ½ mile west of Debbs Creek, 6,000 feet, Pilot Peak (Mus. Vert. Zool.); Harrison Pass R. S. (Mus. Vert. Zool.); west side of Ruby Lake (Mus. Vert. Zool.); between Wells and Wendover, Utah, in Nevada (Univ. Mich.).

Mineral County: Southeast side of Walker Lake, 7.6 miles north of Hawthorne (Mus. Vert. Zool.); Cottonwood Creek, 7,400 feet, Mount Grant (Mus. Vert. Zool.).

Churchill County: 5 miles west of Mountain Well (Mus. Vert. Zool.); 9 miles east of Eastgate, 6,500 feet (Mus. Vert. Zool.).

Lander County: Peterson Creek, 6,500 feet, Shoshone Mountains (Mus. Vert. Zool.); 2 miles northwest of Birch Creek Ranch, 6,000 feet (Mus. Vert. Zool.).

White Pine County: Snake Valley (U. S. N. M.); 5½ miles southwest of Osceola (Mus. Vert. Zool.); Cherry Creek, 6,800 feet (Mus. Vert. Zool.); Deadman Creek, Hendry Creek, and 2 miles west of Smith Creek Cave, Mt. Moriah (Mus. Vert. Zool.); Water Cañon, 10 miles north of Lund (Mus. Vert. Zool.); Spring Valley, 2 miles south of Shoshone (Mus. Vert. Zool.).

Nye County: Last Chance Creek, 6,000 feet (Mus. Vert. Zool.); North Twin River, 6,500 feet (Mus. Vert. Zool.); Peavine Creek (U. S. N. M.); 12 miles north of San Antonio, 5,700 feet (Mus. Vert. Zool.); 7½ miles east of Cliff Spring, 5,900 feet (Mus. Vert. Zool.); 2 miles northwest of Indian Spring, Belted Range (Mus. Vert. Zool.); Big Creek, 5,700 feet, Quinn Cañon Mountains (Mus. Vert. Zool.).

Lincoln County: Garden Valley (Mus. Vert. Zool.); 3½ miles north of Eagle Valley (Mus. Vert. Zool.); Pony Spring, and 4½ miles south (Mus. Vert. Zool.); Pahroc Valley, 24 miles west of Caliente (Mus. Vert. Zool.); 4 miles southwest of Caliente (Mus. Vert. Zool.).

Stomachs of rattlesnakes obtained by Ruthven and Gaige (1915, p. 33) in the upper Humboldt Valley contained small mammals. Females captured on July 6 and 10 contained large eggs (36 mm. long in one). Two specimens captured in Humboldt County on August 7, 1909, at an altitude of 4,300 feet were thought to be a mating pair (Taylor, 1915, p. 356).

A specimen (no. 17022, Mus. Vert. Zool.) obtained on May 24, 1934, at six miles north of Fernley, Lyon County, is considered by Klauber (in letter) to be more like *C. c. oreganus* than *C. c. lutosus* even though the latter would be expected in that area. It is a young individual and young ones show less differentiation in pattern and color than do adults. Until this occurrence is confirmed by the capture of adults, I have considered it best not to include this race in the Nevada list.

Four rattlesnakes were obtained, June 12 to 14, 1932, in Water Cañon, 10 miles north of Lund, White Pine County. One was found before sunrise on the morning of June 12, on broken rocks at the base of a cliff. It was sluggish and did not move while the collector approached and picked it up. In the evening of the same day one was obtained from among broken rocks on a steep hillside. It rattled when a person walked over the rocks under which it was hiding. A partly digested *Lagurus* was taken from its stomach. Another was found near this spot early in the morning on June 14. It was on a flat, oblique rock partly under a small bush. A dead white-footed mouse was suspended on a wire a few inches in front of the snake which rattled and moved forward, all parts of the body appearing to move simultaneously. It stopped near the mouse and bit it immediately with a short, quick motion, the head moving only two or three inches and drawing back as soon as the mouse had been struck. After a few seconds the snake approached and touched the mouse with its tongue and then moved on past it. For five minutes the snake moved restlessly within two feet of the mouse, returning several times to touch the body or move the tongue over its fur. At the end of this time the mouse was grasped by the side of the face and the swallowing commenced. This required eighteen minutes. The snake remained in a loose coil, almost motionless, while the mouse was worked in with slight movements of the jaws. Once the snake rattled in response to slight movements of the observer standing two feet away. When rattling it made no effort to disgorge the prey. After the mouse had been engulfed, a live fence lizard was released on the rock. The snake watched it intently, the tongue far extended and motionless with the tips spread far apart and resting on a dead twig, and the head swaying slightly. It finally began to move cautiously toward the lizard which then ran through the bush and escaped. Apparently in pursuit, the snake crawled quickly about a foot in the same direction and then stopped within the bush where it climbed almost to the top two feet above the ground (Fitch, MS).

Crotalus mitchellii pyrrhus (Cope)

Rattlesnake

Original description.—*Caudisona pyrrha* Cope, Proc. Acad. Nat. Sci. Phila., 1866, p. 308 (Canyon Prieto, Yavapai County, Arizona).

Range.—Southern Nevada, central and western Arizona, southern California, south to northern Lower California.

Occurrence in Nevada.—So far known only from southern Clark County in the vicinity of the Colorado River. Two specimens were obtained in May, 1936, from the vicinity of Nelson, by C. M. Bogert.

Nevada localities (Fig. 28) (No specimens in Museum of Vertebrate Zoology).—

Clark County: Nelson (U. C. L. A.).

Crotalus mitchellii stephensi Klauber

Rattlesnake

Original description.—*Crotalus confluentus stephensi* Klauber, Trans. San Diego Soc. Nat. Hist., vol. 6, no. 3, 1930, p. 108 (2 miles west of Jackass Springs, 6,200 feet, Panamint Mountains, Inyo County, California).

Synonyms for Nevada.—*Crotalus confluentus lutosus* (part), Klauber, 1930, p. 102.

Crotalus tigris, Stejneger, 1893, p. 214.

Crotalus confluentus stephensi Klauber, 1930, p. 109.

Range.—From Mono County to central San Bernardino County in eastern California and eastward into western Nevada.

Occurrence in Nevada.—This race extends from southern Mineral County and the Belted Range, Nye County, southeastward to the Colorado River in the vicinity of Boulder Dam. To the south it intergrades with *C. m. pyrrhus* (Klauber, 1936, p. 163). Altitudinally, its range extends up to around 6,000 feet.

Nevada localities (Fig. 28) (7 specimens in Museum of Vertebrate Zoology).—

Mineral County: Endowment Mine, Excelsior Mountains (Mus. Vert. Zool.).

Esmeralda County: 7 miles north of Arlemont (Mus. Vert. Zool.); McAfee Ranch (Mus. Vert. Zool.); Lida (Klauber, 1936, p. 163); 7 miles south of Tonopah (*ibid.*); 1.7 miles south of Goldfield (Mus. Vert. Zool.).

Nye County: Oak Spring, Belted Range, ½ mile south, ½ mile northwest, and 4 miles southeast (Mus. Vert. Zool.); Grapevine Mountains, above Salt Wells (U. S. N. M.).

Clark County: Indian Spring Valley (U. S. N. M.); Harris Spring, 6,000 feet, Charleston Mountains (Cowles and Bogert, 1936, p. 41); Vegas Valley (U. S. N. M.); Vegas Wash (U. S. N. M.); near Las Vegas (Klauber, 1930, p. 109); Las Vegas Landing (Klauber 1932, p. 127).

Crotalus scutulatus (Kennicott)

Rattlesnake

Original description.—*Caudisona scutulata* Kennicott, Proc. Acad. Nat. Sci. Phila., 1861, p. 207.

Range.—Defined by Klauber (1930, p. 54) as covering parts of Kern, Los Angeles, and San Bernardino counties in California and extending eastward through Arizona to Texas and south to northern Mexico.

Occurrence in Nevada.—Known from two localities in southern part of the state, south of 38° N. and within a few miles of 115° W., and a little more than 100 miles apart. Altitudes were close to 4,000 feet in Pahranagat Valley and 2,000 feet in the vicinity of Las Vegas.

Nevada localities (Fig. 28) (2 specimens in Museum of Vertebrate Zoology).—

Lincoln County: 3 miles southeast of Crystal Spring, Pahranagat Valley (Mus. Vert. Zool.).

Clark County: Indian Spring, 4,000 feet, Virgin Mountains (Mus. Vert. Zool.); 12 miles south of Las Vegas (Klauber, 1932, p. 127).

Subclass Synapsida

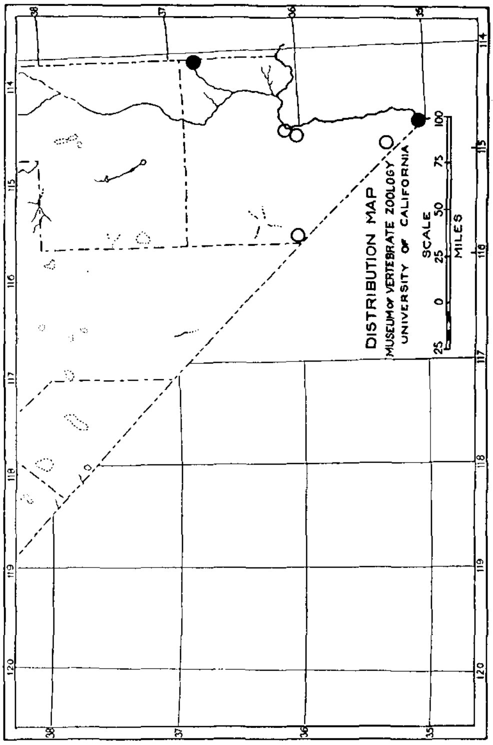
Order **Testudinata**

TESTUDINIDAE

Gopherus agassizii (Cooper)

Desert Tortoise

Original description.—*Xerobates agassizii* Cooper, Proc. Calif. Acad. Sci., vol. 2, 1863, pp.


DISTRIBUTION MAP
MUSEUM OF VERTEBRATE ZOOLOGY
UNIVERSITY OF CALIFORNIA
SCALE
25 0 25 50 75 100
MILES
38
37
36
35
114
115
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120

FIG. 29. Distribution of *Gopherus agassizii* in southern Nevada.

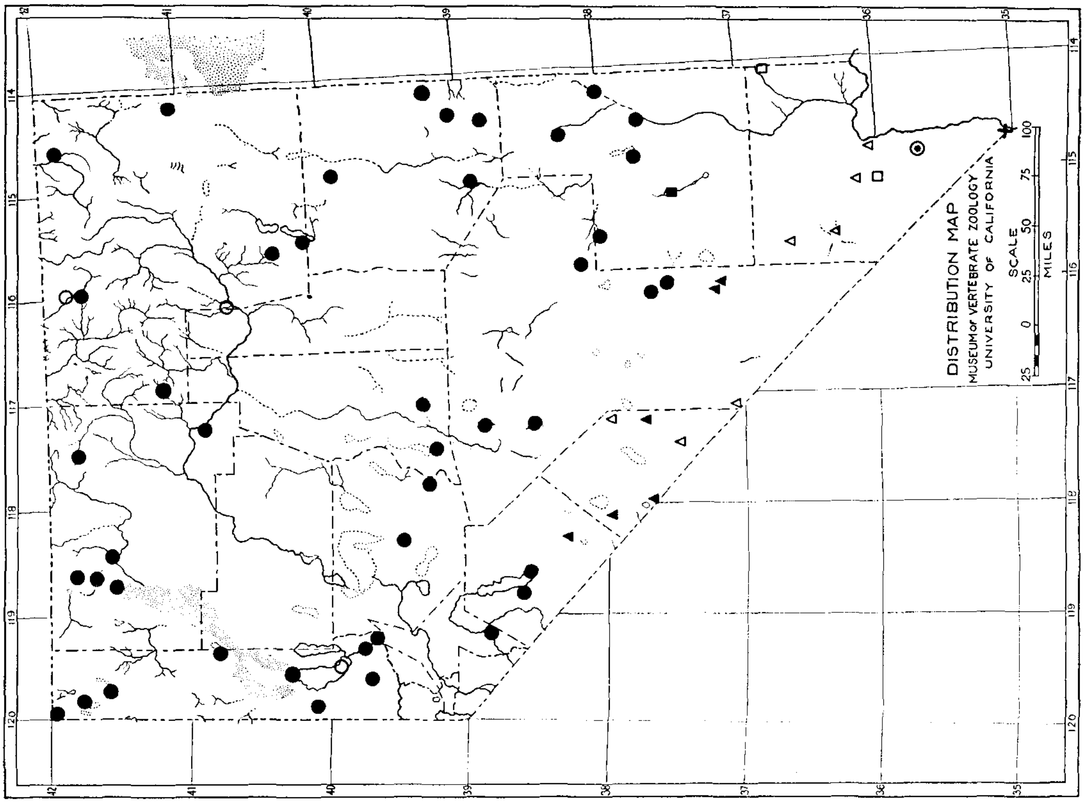
DISTRIBUTION MAP
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FIG. 28. Distribution of *Crotalus confluentus lutosus* (circles), *Crotalus scutulatus* (squares), *Crotalus mitchellii stephensi* (triangles), *Crotalus mitchellii pyrrhus* (dot in circle), and *Crotalus atrox* (cross) in Nevada

120–121 (Mountains of California near Fort Mohave [= Salado Valley, on Mohave Desert]).

Range.—Deserts of southeastern California, southern Nevada and Utah, southwestern Arizona, south into Sonora. Also on Tiburon Island, Lower California.

Occurrence in Nevada.—All records are in southern Clark County, south and east of Pahrump Valley, which is crossed by the 36th parallel. The species doubtless occupies a larger portion of the state than this, for it has been captured in southwestern Utah and north in California to Death Valley. Nevada localities range up to 3,000 feet. Tortoises are found widely scattered over the desert on flat sandy or gravelly ground.

Nevada localities (Fig. 29) (4 specimens in Museum of Vertebrate Zoology).—

Clark County: 4 miles south of Mesquite, 3,000 feet (Mus. Vert. Zool.); Pahrump Valley (U. S. N. M.); near Boulder City (Cowles and Bogert, 1936, p. 42); bend of the Colorado River (U. S. N. M.); Piute Valley, 10 miles south of Searchlight (Klauber, 1932, p. 128); 3 miles northwest of Fort Mojave (Mus. Vert. Zool.); Dead Mountains, 1,000 feet, 114° 40′ W., 35° 5′ N. (Mus. Vert. Zool.).

TRIONYCHIDAE

Trionyx emoryi (Agassiz)

Soft-shelled Turtle

Original description.—*Aspidonectes Emoryi* Agassiz, Contr. Nat. Hist. U. S., vol. 1, 1857, p. 407 (Rio Grande, near Brownsville, Texas).

Range.—Drainage of the Rio Grande in Texas and north to Oklahoma and Arkansas; recently reported from lower Colorado River drainage in Nevada, Arizona, California, and Lower California, but not known to be native in this region.

Occurrence in Nevada.—Present in the Colorado River, apparently for the whole distance it borders southern Nevada. Reported by Cowles and Bogert (1936, p. 42) from the vicinity of Boulder Lake. Commonly caught by fishermen near the California line.

Nevada localities (1 specimen in Museum of Vertebrate Zoology).—

Clark County: Colorado River, 6 miles north of California line (Mus. Vert. Zool.).

GENERAL COMMENT

In this report 63 kinds of amphibians (16) and reptiles (47) are considered, on the basis of specimens examined, to be inhabitants of the state of Nevada. In this lot 56 full species are represented; the only ones having more than one race in this area are as follows: *Bufo boreas* (3), *Callisaurus draconoides* (2), *Uta stansburiana* (2), *Thamnophis ordinoides* (3), and *Crotalus mitchellii* (2). Species recorded that probably have been introduced to Nevada territory by man are *Rana aurora draytonii*, *R. catesbeiana*, *R. pipiens* (part), and *Trionyx emoryi*. One species (*Diadophis amabilis*) reported from the Kingsbury Grade, a few miles from Carson City, Ormsby County, Nevada, by C. P. Russell (Yosemite Nature Notes, vol. 7, 1928, p. 67) was omitted because no specimen was available for verification.

Because of the extremes of dryness reached, the occurrence of amphibians over the whole area is rather discontinuous. This is especially true toward the south end of the state where there are many colonies of amphibians at springs and short streams, surrounded by wide stretches of desert unsuitable for these animals. Apparently this factor of isolation has preserved several colonies of toads and frogs sufficiently distinct from their nearest relatives to deserve recognition by name systematically. Moreover, possibly on account of the higher temperatures and its general location, this southern end of the state has more kinds of amphibians than the northern end. No salamanders have been found in Nevada, but several species may occur and search should be made for them about the mountain lakes. *Bufo alvarius* and *Hyla arenicolor* have been reported close to the borders and they probably occur within the state near its southern tip.

The lizards and snakes are, as a rule, less closely restricted to the immediate vicinity of water than the amphibians, and their ranges are more nearly continuous in Nevada. But these animals are closely adapted to certain types of ground and to other elements in their environment and they vary greatly in density of population. Nearly all the kinds represented reach limits of their ranges somewhere in Nevada. The limiting factor, most often effective in determining this limitation here, appears to be change in air temperature. Additional kinds of reptiles which seem likely to be discovered in Nevada are members of the genus *Gerrhonotus*, and snakes of the genera *Leptotyphlops*, *Diadophis*, *Chilomeniscus*, *Thamnophis*, and *Tantilla*.

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SERPHIDAE IN BALTIC AMBER, WITH THE DESCRIPTION OF A NEW LIVING GENUS

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1. Fossil Species

In 1923 the present writer published a description of a single species of this family from the Baltic Amber.[1]

Later, I received as a loan from the Geological Museum of the University of Königsberg an additional series of specimens and the Haren Collection of amber insects recently acquired by the Museum of Comparative Zoölogy contains also several species of this family. A study of all this material has enabled me to distinguish six clearly defined species, in addition to several others of dubious status that cannot be completely examined on account of unsatisfactory preservation.

In the living fauna the family Serphidae is nearly cosmopolitan, represented by a rather small number of species in a series of genera which are in the main very closely similar to one another. Two Australian genera depart from this general type in possessing a much less reduced wing venation which demonstrates very clearly their more primitive character and a third one from Formosa described in the present paper is also an aberrant form.

It might be expected that the amber fauna would include some primitive types, but this is not the case as all the species are of very ordinary form. Several of the genera as at present recognized are separable on only very slight characters and all of the amber species fall quite readily into one of these. This is *Cryptoserphus* Kieffer, characterized mainly by the extremely short abdominal petiole, and I have referred all of those described in the present paper to this genus. *Serphus cellularis* Brues, known only from the male has a much longer stigma and may not be congeneric. The females may be distinguished by the following key.

Key to the amber Species of Cryptoserphus

1. Penultimate joint of antennae one and one-half to two times as long as thick . . . . 2.
   Penultimate joint of antenna quadrate or slightly transverse . . . . 3.
2. Body, legs, and antennae extremely long and slender; penultimate joint of antennae fully twice as long as wide . . . . *gracilis* sp. nov.
   Body, legs, and antennae not extremely slender; penultimate joint of antennae shorter, not more than one-half longer than wide; radial cell large *pinorum* sp. nov.
3. Radial cell very small, elongate oval *obsolescens* sp. nov.
   Radial cell larger, triangular, with a well developed upper side along the costa . . . . 4.
4. Cauda straight at base, the apical third curved, sharply so at the apex . . . . *hamiferus* sp. nov.
   Cauda quite evenly curved throughout its entire length . . . . 5.
5. Propleura striate; cauda more than three times as long as wide at base . . . . *tertiarius* sp. nov.
   Propleura smooth; cauda less than three times as long as wide at base . . . . *succinalis* sp. nov.

Cryptoserphus gracilis sp. nov.

(Fig. 1, *a*)

♀. Length 4.3 mm., the abdomen greatly extended, so that the length in life was nearer 3.8 mm.; cauda long and slender, about 0.5 mm. in length; antenna 1.7 mm. Color apparently black or very dark with the four anterior legs paler apically. Head small, very strongly narrowed below the eyes so that it appears transversely oval when seen from the front; malar space long, apparently without a furrow; eyes strongly protuberant, bare, about half as high as the head. Antennae very long and slender, not thickened apically; first three flagellar joints subequal; if anything, the first is slightly shorter; second joint almost four times as long as thick and very slightly thickened toward the apex;

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[1] Proc. American Acad. Arts & Sci., vol. 58, p. 344.

penultimate joint twice as long as thick. Ocelli large, in a small triangle. Surface of head smooth, impunctate throughout. Thorax long and slender, almost three times as long as wide at the tegulae (56 : 20); propodeum long, gradually attenuated apically. Legs long, very thin, especially the hind pair and all of the tarsi; apical joint of the four anterior tarsi very slightly swollen, their claws simple, without basal tooth. Abdomen long and narrow; the cauda slender, of even width throughout its length, one and one-quarter times as thick as the basal joints of the antennal flagellum and apparently gently curved, although not visible in direct lateral view. Wings preserved only in part, the neuration not visible in the type.

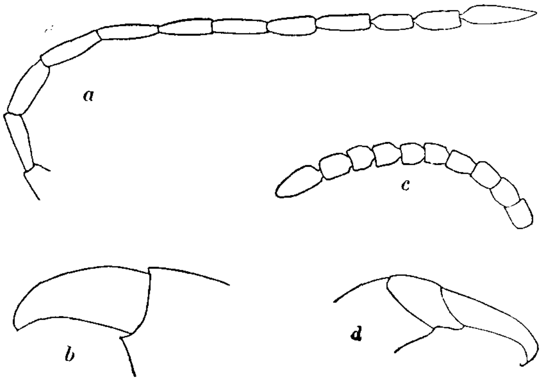

Figure 1. *a, Cryptoserphus gracilis* sp. nov., antenna; *b, Cryptoserphus tertiarus* sp. nov., cauda; *c, Cryptoserphus hamiferus* sp. nov., antenna; *d. Cryptoserphus hamiferus* sp. nov., cauda.

Type: No. 11,024, Collection of the Königsberg Museum.

Although not completely preserved, this species is readily distinguishable from the other amber forms by its remarkably slender body, legs, antennae and cauda.

Cryptoserphus pinorum sp. nov.

(Fig. 2)

♀. Length 2.5 mm. in normal position; with cauda extending backward, 3.5 mm.; antenna 1.2 mm. Apparently black, the tibiae and tarsi piceous; wings hyaline, the stigma and radial vein pale brown. Head large, fully twice as wide as thick, its surface smooth, impunctate; malar space half the width of the eye, with a very distinct furrow; ocelli prominent, in a small triangle. Antennae rather stout; scape scarcely as long as the first flagellar joint which is about twice as long as thick and slightly, but not conspicuously narrower at the base than at the apex; second flagellar joint very slightly longer than the first; following imperceptibly shorter, the penultimate joint one-half longer than thick. Mesonotum rather narrow, the parapsidal furrows quite distinctly impressed on the anterior half. Propleurae not entirely smooth; with several striations along the anterior border, and also some shallow punctate impressions, more noticeable below; mesopleura with a crenate posterior margin. Sides of propodeum rugose-reticulate, without any smooth polished central area; upper surface apparently without any longitudinal carinae. Abdominal petiole extremely short, scarcely visible from above; base of the second segment coarsely striate on the sides, both above and below. Cauda long, only faintly curved, its sides nearly parallel, about seven times as long as wide near the base (44 : 6). Stigma more elongate than usual, the radial cell large; postmarginal vein three-fifths as long as the stigma; first section of

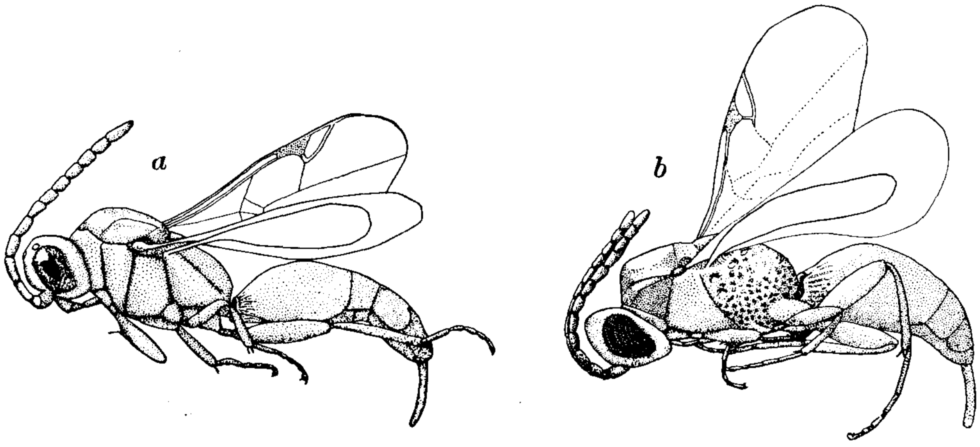

Figure 2. *a, Cryptoserphus pinorum* sp. nov., *b,* probably *C. pinorum.*

radius much thickened, half as long as the width of the stigma; second section not thickened, slightly curved on basal half and slightly divergent from the margin of the stigma. Legs long and slender; last joint of all the tarsi widened apically, but not strongly thickened; tarsal claws simple, without basal tooth.

Type: M. C. Z. No. 8257. Also two females in the collection of the Königsberg Museum, not so completely preserved, but almost certainly the same species, and further, another (No. 7841) most probably the same. Two other specimens are also included with considerable question as these are at least nearest to this species among those described.

Cryptoserphus hamiferus sp. nov.

(Fig. 1, *c* and *d*)

♀. Length 2.1 mm; cauda 0.45 mm. Black, the abdomen apparently rufous or reddish at the base and the legs brownish, especially the four anterior ones; wings hyaline, the stigma and veins reddish brown. Head broad, two and one-half times as wide as thick in vertical view; ocelli in a wide, low triangle, the posterior pair much further from one another than from the eye-margin. Surface smooth and impunctate above; face and clypeus with distinct small punctures, sparse medially and denser at the sides. Malar space shorter than the basal width of the mandible, with a sharp furrow. Antennae short, stout, distinctly thickened apically; scape scarcely longer than broad; first flagellar joint one-half longer than wide at the tip, considerably narrowed toward the base; joints beyond imperceptibly shorter, the penultimate one quadrate, slightly narrower basally, but no longer than the apical width. Thorax rather broad, the mesonotum no longer than its greatest width; parapsidal furrows sharply impressed on their anterior fourth. Pronotum above transversely striate; propleurae smooth, except for a few striae at the extreme lower corner. Propodeum rather finely and evenly rugosely reticulate on the sides, the upper surface not visible in the type specimen. Legs stout, all the femora and tibiae noticeably thickened; last joint of all tarsi not wider than the others, all the claws slender and without a basal tooth. Abdomen short, stout; without striae at the base, except for some very short ones at extreme base below; first segment extremely short, not at all visible from above. Cauda rather long and slender; basal two-thirds straight and only slightly narrowed; apical third sharply narrowed and arcuately curved downward to the tip. Radial cell with its costal margin about half as long as the stigma; first section of radius swollen, punctiform, the second section straight, strongly divergent from the apical margin of the stigma.

Type: M. C. Z. No. 8265.

This species may be recognized by the form of the cauda which is almost hooked at the tip.

Cryptoserphus tertiarius sp. nov.

(Fig. 1, *b*)

♀. Length 3.9 mm.; cauda 0.4 mm. Apparently entirely black; wings hyaline with dark brown stigma and venation. Head rather wide, the cheeks as wide as the eyes; malar space about as long as the width of the mandible at base, with a well developed furrow. Antennae slightly, but distinctly thickened apically; penultimate joint of flagellum quadrate, its length equal to its width; scape short, slightly longer than thick; first flagellar joint about one-half longer than thick, the following joints growing gradually shorter. Face and clypeus apparently not punctate, although not very clearly visible. Mesonotum with no clear indications of parapsidal furrows. Pronotum transversely striate above; propleura striate, except anteriorly near the middle. Propodeum long, not very sharply declivous behind; rather coarsely reticulate above; the sides obliquely striate, except for a large smooth area below the spiracle; a heavy crenate line on each side of the anterior propodeal suture above the middle coxa. Abdomen elongate, the second segment one-third longer than high in lateral view; petiole very short, not visible from above; cauda curved throughout its length, about three times as long as thick near the base. Legs rather stout; front tarsi with the apical joint not at all widened, its claws simple. Radial cell about half as long as the stigma along the costal margin; first section of radius rather short and thick; second section thin, straight.

Type: M. C. Z. No. 8272.

This species is similar to the preceding one, but differs clearly in the shape of the cauda and the conspicuous striation of the propleura. It is also very much larger.

Cryptoserphus obsolescens sp. nov.

♀. Length 3.2 mm.; cauda 0.43 mm. Entirely black, shining, except the tegulae which are light brown, wings hyaline or slightly infuscated, the stigma and veins reddish brown. Head rather wide and thin when seen from above; the ocelli in a small triangle, the posterior pair at least as far from the eye as from one another; surface of head above and on the face and clypeus finely, sparsely punctate, the cheeks smooth. Malar space slightly shorter than the width of the mandible at base, with a sharply defined furrow. Antennae short, very little thickened apically; scape short and stout, scarcely as long as the first flagellar joint which is almost twice as long as wide at tip and very much narrowed toward the base; following joints gradually shorter, the penultimate one as long as wide. Pronotum medially rough, not clearly visible, but apparently not transversely striate. Mesonotum elongate, smooth, anteriorly with only shallow, weak indications of parapsidal furrows. Propleura smooth and shining, very strongly, obliquely concave; mesopleura smooth, except for some shallow longitudinal wrinkles near the the upper edge; its posterior margin with a crenate line. Propodeum coarsely reticulate on the posterior slope and the sides; upper surface apparently smooth. In the type this appears as though it might be due to a layer of occluded air, but the paratype shows the same absence of reticulation on this surface. Sides of propodeum with a large smooth area anterior to and below the spiracle. Petiole of abdomen extremely short, not visible from above; base of second segment with a few very short striae at the base above. Cauda short, a little less than twice as long as high at the base (30 : 17); curved downwards, more noticeably so toward the apex, especially on the dorsal side. Radial cell very short, forming an elongate area that does not extend all the way to the lower corner of the stigma. Legs rather stout, the femora and tibiae noticeably clavate; tarsal claws simple, the last tarsal joint not noticeably enlarged.

Type: No. XXB967; paratype Z128, both in the Königsberg Collection.

This species is most distinct on account of the extremely small radial cell as well as by the sculpture of the propodeum.

Cryptoserphus succinalis sp. nov.

(Fig. 3)

♀. Length 4.5 mm.; cauda 0.7 mm. Apparently entirely black, with the wings distinctly infuscated, especially in front. Head short, surface smooth or nearly impunctate; transverse; ocelli large, in a small triangle, the posterior pair considerably farther from the eye than from one another. Malar space short, with a sharply defined furrow. Antennae short, but not noticeably thickened; scape as long as the first flagellar joint, swollen apically; first flagellar joint much narrowed toward the base, more than twice as long as thick at apex (7 : 17); following joint much shorter; those beyond very gradually shorter, the penultimate one quadrate, or imperceptibly longer than thick. Thorax quite long and narrow in dorsal view, with shallow, poorly defined parapsidal furrows that extend nearly halfway to the scutellum and set off a narrow median lobe that is highly convex in front. Propodeum long above, the posterior slope sharply declivous; coarsely reticulate, with a smooth area below and anterior to the spiracle; propleura smooth, without striate sculpture. Legs stout, especially the front pair and the femora of the hind pair; last joint of front tarsi fully as long as the preceding two joints together; all tarsal claws simple. Abdomen with the petiole very short, not visible from above, second segment with poorly developed striae at the base, its ventral surface clothed with rather long sparse hairs, repeated as a tuft on the venter just before the cauda. Cauda rather stout at the base, evenly curved and narrowed to the apex. Radial cell triangular, its costal edge about half as long as the stigma.

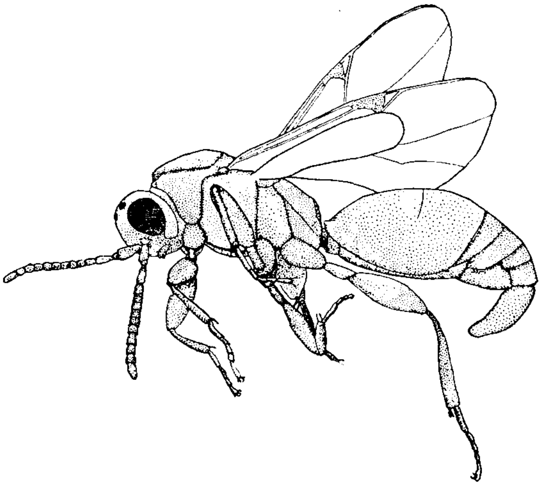

FIGURE 3. *Cryptoserphus succinalis* sp. nov., type specimen.

Type: M. C. Z. No. 8274. Also six other specimens, none of them quite so well preserved, that are probably the same species. No. XXB372 in the Königsberg collection is the best of these and is I believe without question cospecific. Of the others, three belonging to the Königsberg series and two to the M. C. Z. are probably this species.

Most remarkable of all is a block of amber about 33 mm. long, 9 mm. wide and 8 mm. thick which contains a swarm of serphids that seem to belong to this species. These are massed together and so tangled and overlain that it is possible only to estimate the number of specimens in the group.

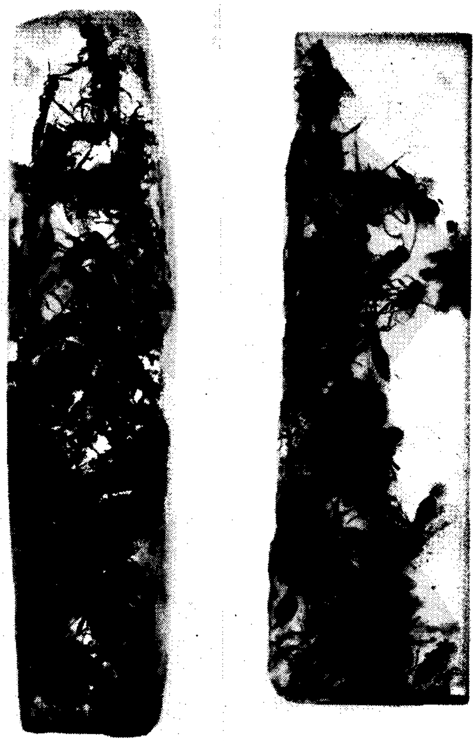

FIGURE 4. Amber block containing aggregation of some 50 specimens, probably *Cryptoserphus succinalis*.

All seem to be females and there are certainly more than fifty altogether. As the crowding is greatest along one side and at one end the number originally must have been much greater. In spite of the large series, it is impossible to view any of them clearly enough to make sure of the specific determination.

I have never seen any comparable swarm of serphids, nor have I seen any accounts of similar aggregations among living species of this group. What may have been the cause of this occurrence in the Oligocene pine forest must remain for the present uncertain.

2. A New Living Genus of Serphidae from Formosa

I have had in my collection of Serphidae for a number of years a remarkable undescribed genus from Formosa. It is represented by only two male specimens, in neither of which are the antennae complete and I have delayed any attempt to describe it in hopes that better material might fall into the hands of some interested entomologist. Meanwhile, Dodd has described two genera from Australia, *Acanthoserphus* and *Austroserphus*, even more unusual than the Formosan genus. Both of Dodd's genera are more generalized than other Serphidae in possessing a much more complete wing venation, but both are highly modified, especially *Acanthoserphus* which has the prothorax and postscutellum spined and the mandibles greatly reduced or absent. In *Austroserphus* the antennal scape and vertex are peculiarly modified and the abdomen has a long petiole in the male. Both, however, possess 13-jointed antennae and in the general structure of the body are without the slightest question true Serphidae. The present genus is close to the very uniform series of other genera known from widespread points throughout the world, although the head and thorax are greatly modified and the antennae have more than thirteen joints which is the number always present in all the other known genera of the family.

Nothoserphus gen. nov.

♂. Head wide, and very thin antero-posteriorly, three times as wide as long in dorsal view; at the sides, between the eyes and occipital foramen, fully four times as wide as long; in facial view the head is slightly wider than long, much narrowed below the eyes. Clypeus transverse, with deeply impressed lateral foveae, convex, its lower margin with reflexed margin that extends as a marginal carina along the posterior edge of the malar space almost to the eye; mandibles concealed beneath the clypeus, but the palpi are long and projecting. Antennae with more than 13 joints (all lack the tips, but I suspect from the form of one with 13 joints that the complete antenna may probably be 14 or 15-jointed), inserted well above the clypeus, just above the lower margin of the eyes; scape small, pedicel very short; flagellum filiform, slender, joints of approximately equal length, but thinner toward the apex of the antenna. Vertex sharp above, forming a straight transverse edge which bears a rounded, blade-like elevation on each side external to which the posterior ocelli lie; between these elevations is a deep semicircular excavation; ocelli large, in a triangle. Occipital margin narrowly reflexed. Thorax short; pronotum with the humeri angularly elevated; mesonotum with parapsidal furrows meeting before the scutellum and with similar furrows near the sides; scutellum raised, but not spined, with a deep basal impression. Propodeum much narrowed behind, reticulate, but without any longitudinal carinae. Petiole of abdomen short, scarcely visible above as in *Cryptoserphus;* second segment long, almost entirely covering the abdomen; tip of abdomen bispinose as usual. Wings ample; venation as in *Serphus,* with a large triangular stigma and short radial cell, but without discal venation. Legs slender; claws of front tarsi with a fleshy lobe at the base.

Type: *N. mirabilis* sp. nov.

In spite of the unusual form of the antennae I think that *Nothoserphus* must be placed in the Serphidae, particularly on account of the wing venation and the form of the abdomen which do not depart in the least from the typical members of the family.

Nothoserphus mirabilis sp. nov.

♂. Length 3.5–4 mm. Body entirely black and shining; antennae pale brownish at the base, third and fourth joints darker, remainder black; tegulae dark brown; legs beyond the coxae pale honey yellow, the tips of the hind tibiae infuscated; wings tinged with brownish, below the stigma with a diffuse brown cloud, the stigma and veins deep brown. Head very highly polished, especially on the front and the posterior surface. Ocelli in a curved line or low triangle, the posterior ones lying just external to the elevated lobe on the vertex close to its sharp upper edge. The elevated lobes are so thin that their edges are broken in one specimen. Front nearly flat, the orbits vertical, clypeus highly convex medially. First flagellar joint slightly more than three times as long as thick; following very little shorter and thinner, retaining about the same proportions. Head bare above, sparsely hairy below the antennae. Pronotum vertical, with a large fovea on each side of the median line and some smaller crenate sculpture, its upper angles elevated a blunt tooth, behind which the pleura is sparsely hairy. Mesonotum smooth, slightly wider than long, parapsidal furrows deep, transversely striate, entering two approximated shallow depressions well in front of the scutellum; lateral grooves coarsely crenate, extending just to the tegulae; median lobe very convex, tapering to a point behind, as wide as long. Scutellar groove wide and deep, enclosing three pits, disc sharply convex. Metanotum irregularly, coarsely striate. Propodeum elongate, evenly narrowed, coarsely reticulated, the posterior dorsal face small, slightly concave, but not separated by distinct carinae; basally above with a broad, shallow median impression. Propleura vertically excavated, its surface shallowly, very irregularly, confluently wrinkled or pitted; mesopleura smooth with a large shallow impression near the middle and a crenate submarginal line behind. Petiole of abdomen as long as high, but shorter above so that it appears much shorter than wide in dorsal view, coarsely and irregularly sculptured; second tergite with a single groove or broad stria medially at the base that extends to the basal fourth; otherwise polished and entirely smooth except for a broad apical band of very small, sparse punctures; sides of the compressed third segment similarly punctate. Stigma large, triangular, radial cell small, its costal edge less than half the length of the stigma; first section of radius practically wanting, the straight second section enlarged at the base which is contiguous with the stigma.

Type and paratype from Taihorin, Formosa, July 7, 1911 (H. Sauter).

CALLICERATIDAE IN BALTIC AMBER

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Up to the present time no members of this family of parasitic Hymenoptera have been described from the Baltic amber, although a single species is known from the Cretaceous amber of Canada.

The material at present in my hands includes altogether almost fifty specimens among which I have been able to recognize the five species which are described on the following pages. This material comes in part from the Haren collection belonging to the Museum of Comparative Zoölogy at Harvard University and in part from specimens loaned me for study by the University of Königsberg.

The family Calliceratidae includes about 500 recent species distributed in something over twenty genera. These are divided into two distinct subfamilies on the basis of the form of the stigma. This is linear in the typical subfamily Calliceratinae of which there are two species in the amber, and triangular in the Megaspilinae of which three amber species are described in the present paper.

Subfamily CALLICERATINAE

Lagynodes Förster

There are in the present material two species that I have referred to this living genus which is known to be widely distributed in the Palaearctic region. As in the living species they are dimorphic, the males being alate and the females completely apterous. The males of the fossil species seem to be fairly typical, except that the stigma is distinctly incrassate, at least twice as thick as the apex of the submarginal vein, whereas in the several living species the stigma is clearly linear and not noticeably thicker than the submarginal vein. The females show a more complete development of the short, dorsal, impressed lines on the second tergite of the abdomen so that these outline a complete trident rather than the M-shaped series of lines that are present in the living forms. Another characteristic is the larger mesonotum; this is very greatly reduced in the living species and although small in the two fossil ones the reduction has obviously not progressed so far. Taken together the several differences seem to indicate very clearly that the Oligocene forms are close to the recent genus *Lagynodes*, but more generalized and quite possibly nearly in the line of origin of the present-day species.

The two amber species may be separated as follows:

1. Wings present, fully developed (males) . . . . 2.
   Wings entirely wanting (females) . . . . 3.
2. Very small species; length 0.7 mm. *L. primordialis* sp. nov.
   Larger species; body at least 0.85 mm. in length. *L. electriphilus* sp. nov.
3. Length 1.0 mm. . . . . *L. primordialis* sp. nov.
   Length 1.25 mm. . . . . *L. electriphilus* sp. nov.

Lagynodes primordialis sp. nov.

(Fig. 1 and Fig. 2, *a* & *b*)

♂. Length 0.75 mm. Apparently entirely black, including the legs; wings hyaline with piceous venation. Head above smooth or slightly punctulate, the ocelli forming a small triangle on the vertex. Eyes rather large, widely separated above by three times the width of the ocellar triangle, but extending down well toward the mandibles so that the malar space is less than one-fourth the width of the eye. Antennae inserted high on the head, at about the middle of the eye; scape slender, about three times as long as wide, barely shorter than the pedicel and first flagellar joint combined; pedicel slightly longer than wide and two-thirds as thick as the scape; first flagellar joint three times as long as thick; following gradually shorter, except for the longer apical joint. Mesonotum smooth and subshining, with parapsidal furrows and a complete median groove; these are thinly and finely impressed, but very distinct; the parapsidal furrows are not very widely separated and weakly convergent behind so that they are separated at the base of the scutellum by half the distance that separates them on the anterior part of the mesonotum; posterior suture of mesonotum marked by a very fine, sharp line. Scutellum convex, polished, separated from the axillae by a straight, crenate line which bears a deep punctate impression at its outer end. Propodeum very short in dorsal view, longitudinally rugose. Abdomen apparently with several short basal carinae, although these are obscured in the type, length of the tergites not clearly visible. Legs slender, but with the femora distinctly clavate.

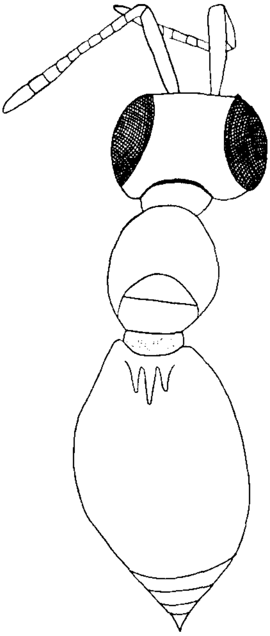

FIGURE 1. *Lagynodes primordialis* sp. nov. ♀

Wings with a long marginal fringe apically; marginal vein linear, short, slightly, but not conspicuously widened at tip; radial (stigmal) vein short, slightly curved, leaving more than half of the cell open at apex.

♀. Length 1.0 mm. Completely apterous. Color apparently dark brown or piceous, but in one or two specimens noticeably lighter, especially on the legs. Head rounded, not noticeably extended at the insertion of the antennae; front and vertex quite evenly convex, the surface finely shagreened; cheeks and temples shining, sparsely punctulate; clypeus with a rather sharp median impression. Eyes comparatively large for the genus, about twice as long as the malar space, elongate oval; vertex sharply excavated and with a raised marginal line. Antennae 11-jointed scape long, thick, of uniform width, more than half as long as the following joints together flagellum noticeably thickened apically, the joints about quadrate, except the last which is conical and about twice as long. Thorax above smooth or minutely shagreened. Prothorax very much elongated above; exclusive of the anteriorly contracted neck, it is about as long as the remainder of the thorax; mesonotum reduced to a small plate, about twice as wide as long, that does not extend quite to the sides of the thorax, its anterior margin arcuate, the posterior one straight.

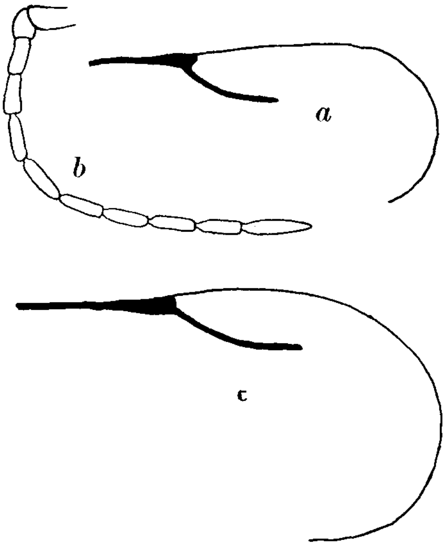

FIGURE 2. *a*, *Lagynodes primordialis* sp. nov., tip of wing of male; *b*, antenna of same; *c*, *Lagynodes electriphilus* sp. nov., tip of wing of male.

Scutellum transverse, nearly as long as the mesonotum; propodeum visible from above only as a nearly linear band. Second tergite covering most (about three-fourths) of the abdomen; the following segments very short, slightly decreasing in length; entire surface smooth, the second tergite at the base with three V-shaped elevations, each one slightly raised and marked off by finely impressed lines each of which ends in a large puncture or fovea at the base. This trident-like elevation has the three parts each acutely lanceolate distally and they are contiguous basally. Femora thickened, their tibiae clavate.

Type ♀, No. 9793, Museum of Comparative Zoölogy. Three paratypes from the University of Königsberg, one of them numbered 206. Two allotype males, one in the Königsberg collection and the other in the Museum of Comparative Zoölogy, No. 9794.

Lagynodes electriphilus sp. nov.

(Fig. 2, *c*)

♂. Length 0.85–1.0 mm. Body brown or piceous; the legs lighter, fuscous or brown, the specimens varying but none appearing entirely black as preserved. Wings hyaline, the venation dark brown. Head above shining, scarcely punctulate; ocelli large, in a small triangle, the posterior pair occupying less than one-third of the width of the front between the eyes. Malar space short, about one-third as long as the width of the eye. Antennae long and slender, inserted at the level of the middle of the eye; scape thicker apically, three times as long as wide; pedicel one-third as long, more or less globular; first flagellar joint nearly as long as the scape which is not so long as the pedicel and first flagellar joint combined; following joints shorter and subequal, except for the longer apical one. Mesonotum not distinctly sculptured, with the parapsidal furrows and a median groove disposed as in the preceding species, although the mesonotal lobes and scutellum appear to be more strongly convex and the basal groove of the scutellum more deeply impressed laterally. Propodeum short, rugose. Abdomen highly polished, the second tergite occupying two-thirds the entire dorsal length. Legs slender, the femora slightly thickened, the tibiae very slender basally. Wings with the marginal vein slightly widened apically; radial vein complete to beyond its basal half so that the cell is open for slightly less than its apical half.

♀. Length 1.25 mm. Completely apterous. Very similar to the female of the preceding species and associated with the males of the present species mainly on account of its size which is in the single specimen larger than the several females of *L. primordialis*, which vary practically not at all in the present series. This difference in size is one of the differential characters among the males of the two species. Color as preserved, brownish, very clearly pale and probably more or less ferruginous or fulvous in life. Eyes very coarsely hairy (probably so in both species, but not visibly preserved in *L. primordialis*). Head above closely, minutely punctate, the thorax above more conspicuously so, otherwise structurally similar to *L. primordialis*. Abdomen coarsely, conspicuously hairy. Trident-like ridges at base of second tergite shorter, the median one not as long as the mesonotum and scutellum together. The depressed areas between the ridges deeply impressed basally, but the excavation is not set off as a distinct fovea.

Type ♂, in the Collection of the Königsberg Museum which contains also six other male specimens. Allotype ♀, a single specimen in the collection of the Museum of Comparative Zoölogy, No. 9795; no further females.

It is possible that I have not associated the females of the two apterous species correctly as there are no really clear differences except for size. The males are, however, quite obviously separable into two distinct species.

Subfamily MEGASPILINAE

Conostigmus Dahlbom

Three amber species in the present collection are referable to this genus. They agree closely with the recent members which are numerous and widespread throughout the Holarctic region. The stigma in the wings appears to be narrower in all the fossil forms than in any living species with which I am familiar, but otherwise the amber forms seem to be quite typical. The abundance of members of this genus in Baltic amber is especially interesting in view of the fact that a species tentatively referred to the related *Lygocerus* has been described by the writer from the earlier Cretaceous amber of Manitoba.[1] They may be distinguished by the following key.

1. Very small species, female 0.74 mm. in length; joints near the middle of the flagellum no longer than wide................*C. juvenilis* sp. nov.
   Larger species, females at least 1.1 mm. in length..2.
2. Antennae stout throughout; middle joints of flagellum (♀) quadrate, not longer than thick; pedicel and first flagellar joint not elongated, the latter less than twice as long as thick. *C. succinalis* sp. nov.
   Antennae more slender, especially at the base of the flagellum; middle joints longer than thick; pedicel and first flagellar joint much elongated, each more than twice as long as thick. *C. resinae* sp. nov.

Conostigmus juvenilis sp. nov.

(Fig. 3)

♀. Length 0.74 mm. Apparently black, with the abdomen and the base of the antennae brownish; wings hyaline, the stigma and venation

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[1] Univ. of Toronto Studies, Geol. Ser., No. 40, p. 43, 1937.

rather light brown, although obviously faded in the type specimen. Head smooth and shining. Eyes comparatively small, much higher than wide, without any visible hairs. Cheeks and lower part of temples very broad, fully equalling the width of the eye. Ocelli large, in a very small triangle. Antennae 11-jointed, the scape extending to the level of the top of the eyes, as long as the following five joints taken together; pedicel nearly twice as long as thick near apex, narrowed basally; first flagellar joint much shorter than the pedicel and thinner; second and following joints of flagellum growing broader and slightly longer toward apex, all of them clearly longer than wide; last joint gradually tapered to a point, twice as long as the preceding one. Mesonotum highly convex, almost gibbous medially in front, with three deep furrows that meet behind barely before the scutellum. Axillae triangular, more acute inwardly, apparently not quite meeting on the median line; disc of scutellum shining, feebly convex. Propodeum above finely rugose-reticulate. Petiole of abdomen very short; second segment smooth, with a marginal carina and a series of large closely placed punctures at the base, but without any basal striae or grooves; abdomen narrow, about two and one-fourth times as long as broad, gradually attenuated from near the middle to the narrowly acute apex. Stigma only moderately wide, about twice as long as broad, convex below, but more or less narrowed basally, the distal margin also convex; basal two-thirds of radial vein complete, leaving the apical third of the radial cell open.

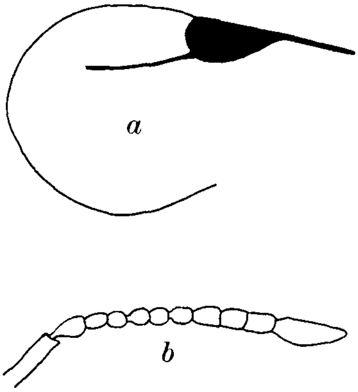

FIGURE 3. *Conostigmus juvenilis* sp. nov., male. *a*, tip of wing; *b*, antenna.

Type and paratype in the Collection of the Königsberg Museum, the type without number and the paratype numbered 11,036.

Conostigmus succinalis sp. nov.

(Figs. 4 & 5)

♀. Length; type 1.6 mm., other specimens 1.1 mm. to 1.7 mm. Apparently entirely black; wings subhyaline, with very dark stigma and veins. Head large, rounded, surface shallowly punctulate or shagreened on the front and vertex; front between the eyes not occupying quite one-half the width of the head; ocelli in an equilateral triangle, separated by somewhat less than the distance between the lateral ones and the eye margin. Eyes coarsely granulated, apparently not hairy; large, several times wider than the cheeks which are much broader than the lower part of the temples; surface of head behind the eyes smooth and polished. Antennae 11-jointed, very stout; scape long and stout; pedicel and first antennal joint not elongated, the latter less than twice as long as thick; following joints all barely longer than thick, the apical one elongated and pointed as usual. Thorax shining, its upper surface minutely punctate or slightly shagreened. Median suture and parapsidal furrows finely, but very sharply impressed as lines of closely set punctures; the suture between the mesonotum and axillae is a fine, impressed, non-punctate line; scutellum separated from the axillae by a sharply punctate line on each side, the inner angles of the acutely triangular axillae meeting in a point on the median line. Surface of scutellum very minutely punctate-reticulate, its apex margined by a punctate frenum. Propodeum sharply, irregularly reticulate; with a series of very short and closely placed longitudinal ridges at apex. Base of abdomen longitudinally fluted with the dorsal grooves extending at least to the

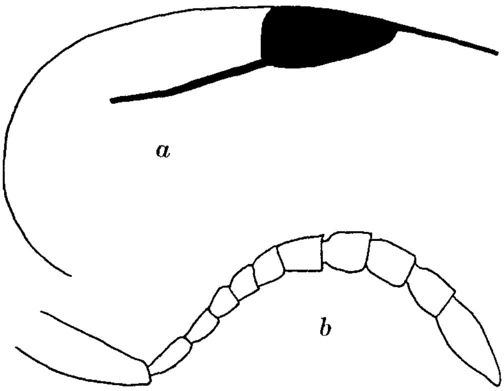

FIGURE 4. *Conostigmus succinalis* sp. nov., female. *a*, tip of wing; *b*, antenna.

basal third of the second tergite which occupies about one-half the length of the abdomen; following segments subequal; body of abdomen broad, not much more than twice as long as wide.

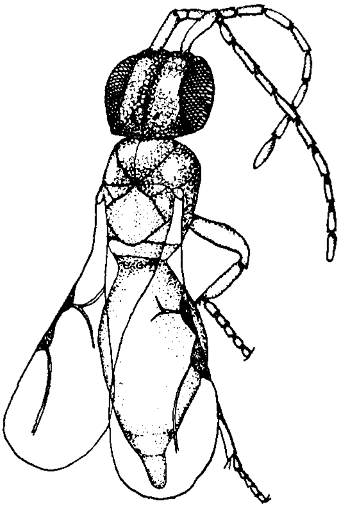

FIGURE 5. *Conostigmus succinalis* sp. nov., male.

Legs stout, the front and hind femora strongly thickened. Stigma about twice as wide as long, subtriangular, with the posterior and apical margins slightly convex; radial vein extending two-thirds of the distance to the margin of the wing, leaving the apical third of the radial cell open.

Type, No. XXB1349, University of Königsberg Museum and two other females designated as paratypes, one in the Königsberg Collection and the other, No. 9796 in the Museum of Comparative Zoölogy. Seven other specimens are probably this species also although these are not so well preserved.

Conostigmus resinae sp. nov.

♀. Length 1.6 mm. Apparently entirely black; possibly with the legs pale although this seems to be due to a bleaching of these in the type specimen; wings hyaline. Very similar in most characters to the preceding species. Head smooth and shining. Antennae with the pedicel narrow, although thicker distally, fully three times as long as wide; first flagellar joint slightly more than twice as long as thick; following joints shorter and decidedly thicker beyond the third joint, the apical ones more than twice as thick as the first flagellar joint and all longer than wide. Mesonotum smooth, the middle lobe highly convex in front; parapsidal furrows approaching the median furrow at an angle of about 45° but reaching the posterior margin at a point well separated from the median line. Second tergite of abdomen extending about half way to the tip; smooth, without striae or grooves at the base. Stigma more than half as wide as long, more or less triangular, but with the lower and outer sides distinctly convex; radial vein long, extending fully two-thirds the distance from the stigma to the wing margin, of uniform thickness throughout.

Type in the Königsberg collection. It is not so well preserved as might be wished, but is evidently distinct from the other specimens before me.

THE OLD WORLD SPECIES OF THE CELASTRACEOUS GENUS MICROTROPIS WALLICH

BY E. D. MERRILL AND F. L. FREEMAN

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Up to the end of 1938 forty-four binomials had been published under *Microtropis* Wallich, approximately ten of which, in accordance with the present study, appertain to genera other than *Microtropis*, or are synonyms of other species of the genus as we at present understand them. It is significant that up to the close of the last century but eighteen of these had been published, all but one appertaining to Old World species, the distinctly large increase in proposed species coming within the present century. At least up to a couple of decades ago the genus was considered to be a small one. No previous attempt has been made to consider, at one time, other than the relatively few species that occur in restricted areas covered by published floras or enumerations, such as those appertaining to India, Ceylon, Burma, Siam, the Malay Peninsula, Indo-China, Japan, the Philippines, and Central America and Mexico. A study of the group was undertaken under the impression that if one assembled the necessary historical material a considerable number of reductions might be possible. This idea has proved to be erroneous, for in connection with a rather intensive study of much or all the material in fourteen different herbaria, while a very few reductions have been made, a considerable number of apparently hitherto undescribed species have been detected, the net result being to increase the Old World species from about forty recognized in 1938 to sixty-four.

The status of the accepted generic name has seemed to us to be worthy of some consideration, partly because of the fact that the earlier leguminous genus *Microtropis* E. Meyer (Nov. 1835) actually invalidates *Microtropis* Wallich, which, although proposed in 1830, was not actually validated by the publication of a technical generic description until 1837, when a description was supplied by Meisner. Because of the general use of *Microtropis* Wallich for this particular group of plants since 1837, and because *Microtropis* E. Meyer (Nov. 1835) is actually a synonym of *Euchlora* Ecklon & Zeyher (Dec. 1835), we believe, with Mansfeld, Repert. Sp. Nov. **39**: 37. 1935, that *Microtropis* Wallich (1830–37) should be conserved against *Microtropis* E. Meyer (1835), although three other valid generic names are now available for the celastraceous genus with which we are concerned in *Paracelastrus* Miquel (1859), *Otherodendron* Makino (1909), and *Chingithamnus* Handel-Mazzetti (1932). Even although the genus *Microtropis* Wallich contains no species known to be of economic or horticultural importance we scarcely feel justified in advocating its abandonment and in the acceptance of *Paracelastrus* Miquel in its place under existing circumstances.

Under *Microtropis*, Wallich, List, p. 152. 1830, proposed the following binomials: *M. discolor* Wall., *M. ? coriacea* Wall., *M. longifolia* Wall., and *M. ? bivalvis* Wall. The first was based on *Cassine discolor* Wall. (1824) and the last on *Celastrus ? bivalvis* Jack (1820). *Microtropis ? coriacea* Wall. is apparently a synonym of *Salacia flavescens* Kurz (1872) of the Hippocrateaceae. *Microtropis longifolia* Wall. remained a *nomen nudum* until 1873 when Kurz published a technical description of it.

In 1837, Meisner, Pl. Vasc. Gen. Tabl. Diagn. 69, Comment. 49. 1837, published the first technical description of *Microtropis* Wallich, based on *M. discolor* Wall. and *M. bivalvis* Wall. As no flowers of the latter were available, we unhesitatingly accept *M. discolor* Wall. as the type or standard species of the genus. Arnott published a more amplified generic description two years later, Ann. Nat. Hist. **3**: 151. 1839. We call special attention to the fact that *Microtropis* Wallich as typified by *M. discolor* Wall. presents certain characters that do not hold for the majority of the species now placed in that genus. These are the absence of the disk, the short filaments alternating with the petals and slightly uniting their bases, the petals carinate inside, and the fruits distinctly subfurfuraceous-lepidotulate. If one wished to segregate genera here, one could restrict *Microtropis* Wallich to a very few species, among those now known, and adopt *Paracelastrus* Miquel for the majority of the species in which the disk is distinctly developed; or if one wished to restrict *Paracelastrus* Miquel to the group that we have designated as *Filiformes*, then *Otherodendron* Makino and *Chingithamnus* Handel-Mazzetti would be available for other groups, the former for those species with peduncled cymes, and the latter for those with sessile lateral fascicles or glomerules.

Paracelastrus Miquel, Fl. Ind. Bat. **1** (2): 591. 1859, which is a synonym of *Microtropis* Wallich, as we have interpreted the latter genus, has had a somewhat peculiar history. King, Jour. As. Soc. Bengal **65** (2): 342. 1896 (Mater. Fl. Malay. Penin. **2**: 628) definitely states that the plant issued by Wallich as *Microtropis ? bivalvis* Wall. is not, as Wallich supposed, the one described in 1820 as *Celastrus ? bivalvis* Jack, because Jack indicated his plant as apetalous. It was for the latter reason that Miquel in 1859 proposed the new generic name *Paracelastrus*, based wholly on Jack's original description of *Celastrus ? bivalvis*. King thought that *Euonymus capillaceus* Wall. might be the "lost" *Celastrus ? bivalvis* Jack.

As to whether or not *Wallich 4340*, representing *Microtropis ? bivalvis* Wall., actually represents *Celastrus ? bivalvis* Jack, it seems to us that this can best be judged by the following facts: Jack's original specimen was undoubtedly lost when his herbarium was destroyed by fire, February 2, 1824, while in transit on the "Fame" from Bencoolen, Sumatra to England. It had been collected by him on Prince of Wales Island = Penang. In a letter written from that place, March 9, 1819, he not only mentioned the species but stated that specimens of it were included in a parcel being forwarded to Wallich; and *Wallich 4340* (Wallich List p. 152), issued as *Microtropis ? bivalvis* Wall. consists of two Penang collections, "G. Porter" and "Guilielm. Jack." Wallich cites *Celastrus bivalvis* Jack as a synonym. Jack again mentions the species in a letter written in Bencoolen, Sumatra, September 19, 1920,[1] stating that he was then about to publish the species. Jack arrived in Bencoolen from Penang in July or August, 1819. It seems to us that *Wallich 4340*, consisting in part of Penang material actually collected by Jack and sent by him to Wallich, is as close to the type collection for both *Celastrus ? bivalvis* Jack and *Microtropis ? bivalvis* Wall. as can now be determined. We therefore believe that the genus *Paracelastrus* Miquel, which was based wholly on *Celastrus ? bivalvis* Jack, is a synonym of *Microtropis* Wallich; at least as long as we are content to consider that *Microtropis bivalvis* Wall. is congeneric with *Microtropis discolor* Wall. King's surmise that *Celastrus ? bivalvis* Jack was lost, and that *Wallich 4340* did not represent the species does not appear to us to be justified from the record as given above. Undoubtedly Jack's statement that his *Celastrus ? bivalvis* was apetalous was due to the fact that he based his description on material from which the petals had fallen. The several sheets of *Wallich 4340* that we have seen are all in fruit. We again call attention to the fact that *Paracelastrus* Miquel is characterized by the presence of a distinct disk, the stamens being borne on its margin, while *Microtropis* Wallich as typified by *M. discolor* Wall. has no trace of a disk, the filaments being attached near the bases of the petals and alternate with them.

The case of *Paracelastrus* is of further interest because in 1905, F. N. Williams, Bull. Herb. Boiss. II. **5**: 224. 1905, in discussing *Celastrus bivalvis* Jack, did not accept King's conclusions and definitely accepted *Paracelastrus* as the proper generic name for the group that had hitherto passed as *Microtropis* Wallich, and transferred five additional binomials to *Paracelastrus*. These were overlooked by the compilers of the supplements to Index Kewensis until 1938, when they were included in Suppl. 9.

The second alternative generic name is *Otherodendron* Makino, Bot. Mag. Tokyo **23**: 62. 1909, based on *Elaeodendron japonicum* Franch. & Sav. This was reduced to *Microtropis* Wallich by Hallier f., Meded. Rijks Herb. Leiden **1910**: 33. 1911, and we see no valid reason for attempting to maintain it as a distinct genus or even as a subgenus or as a section. One could conceivably segregate from what we have included in *Microtropis* various minor categories, perhaps distinguishable by the number of ovary cells (1-celled or 2-celled), by certain inflorescence characters, or by disk characters, but intermediates as to cell and disk characters impress us as rendering such segregations of highly doubtful value. Thus if we bring together the few species that have no disk as opposed to the majority of the species in which the disk is well developed, the assemblage would be a very unnatural one made up of otherwise totally unrelated species. We are satisfied to include *Otherodendron* in the synonymy of *Microtropis* Wallich, although some Japanese botanists still recognize the former as a valid genus.

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[1] Burkill, I. H. William Jack's letters to Nathaniel Wallich, 1818–21. Jour. Straits Branch Roy. As. Soc. **73**: 147, 268. 1916.

Chingithamnus Handel-Mazzetti, Sinensia **2:** 128. 1932, the last generic name to be considered, is quickly disposed of. The genus was described as the basis of a new plant family, the Chingithamnaceae. The type, *Chingithamnus osmanthoides* Hand.-Maz., is clearly a *Microtropis*, as we have interpreted the latter genus, and is very closely allied to *Microtropis latifolia* Wight, differing only by certain more or less obscure characters. In the following year, Sinensia **3:** 189. 1933, Handel-Mazzetti transferred the species to *Microtropis*, as *M. osmanthoides* Hand.-Maz.

The geographic distribution of *Microtropis* in the Old World is interesting in that there is not a single widely distributed species, that is, one even approaching the generic range of the group as a whole. As we have interpreted *Microtropis discolor* Wall., its range extends from Silhet, Bengal and Assam to Yunnan, occurring also in Burma, Siam and Indo-China, and very doubtfully in Penang; and in our present interpretation of its specific limits we have frankly treated this as a species *sensu latiore*. Doubtless future investigators, working with more abundant material, at least from the periphery of the range as given above, may find it possible and convenient to segregate certain forms either as varieties or as distinct species. This is very apt to be the case for the Penang and the Indo-China forms, still represented by inadequate material. The second rather widely distributed pecies is *Microtropis fokienensis* Dunn, with a ange from Formosa, through southern China to Yunnan; and yet in this assemblage we are able o detect local forms distinguishable by minor but ften rather intangible characters. Some of hese forms may eventually be found to represent listinct categories, whether as species or as arieties. With the exception of these two pecies, all other forms are peculiarly restricted n geographic range, being confined to this or hat part of this or that country, to this or that land, or even to single mountains as far as vailable collections indicate. Thus two species re confined to Ceylon, and others to southern eninsular India. Others are known only from estricted areas in India, Burma, Siam, Indo-China, the Malay Peninsula, or from certain provinces or contiguous provinces in southern China. Still others are known only from single localities in Java, Borneo, Luzon, Catanduanes, Panay, and Basilan, and as to the Luzon species, the individual ones are generally known only from strictly restricted areas. The generic range in the Old World is from Silhet and Assam, southern peninsular India and Ceylon to central Japan and Formosa, southward through Burma, Siam, Indo-China, and the Malay Peninsula, to Sumatra, Java, Borneo, and the Philippines, in the latter group from northern Luzon to Basilan in the extreme south. No representative of the genus is known from Celebes, the Moluccas, the Lesser Sunda Islands or from the Papuan region. For restricted areas within the Old World range of the genus there are at present known eighteen species in China, including Hainan, nine in Burma, eight each for the Malay Peninsula (including Penang), Borneo, and the Philippines, five each for India and Indo-China, four in Siam, three each in Sumatra and in Japan-Formosa, two in Ceylon, and one in Java.

In such a group as this, where many of the recognized species are known only from single or very few collections, it is perhaps unwise to generalize on problems of geographic distribution. Yet in surveying the group as a whole, one is immediately impressed with the tremendously developed local endemism, which it is difficult to explain. As an illustration of how local or rare individual species may be, in all the field work that has been prosecuted in the botanically very well known island of Java in the past 200 years, *Microtropis* is represented in extant Javan botanical collections by only one species, based on a single collection, and Dr. S. H. Koorders, its collector, notes that it was very rare. In 1892 Haviland collected *Microtropis suborbiculata* Merr & Freem. on Mount Kinabalu, and this particular species still remains represented only by the type collection, although Mount Kinabalu has been intensively explored by a considerable number of collectors and botanists in the present century, and all of them ascended the mountain by the same route that Haviland followed. Yet these more recent explorers secured representatives of no less than four additional species of *Microtropis* on Mount Kinabalu, all very different from the one form that Haviland collected. In the twenty-one years that the senior author lived in the Philippines, from which group no less than eight species are now known, he never actually saw a

Microtropis in the field, although a total of several years was devoted to botanical exploration, including trips, at various times, into regions where the species are known to occur. Mr. A. D. E. Elmer's even more extensive field work from 1904 to date, in the Philippines, yielded but one species. All the Philippine species being small shrubs, they would not, if in flower or fruit, be consistently overlooked by any collector unless they were very rare or very local. Out of the total of sixty-four species considered in this paper no less than twenty are represented in the fourteen herbaria listed below by only single collections. We are impressed by the fact that the genus is not well represented in any large herbarium if we can judge by the material in the fourteen collections studied.

Within the tropics many of the species are confined to higher altitudes, this being true of all of the species of Java and Borneo, most of those in the Malay Peninsula, and most of the Philippine species. This is apparently true of the species of peninsular India and Ceylon, as well as perhaps most of those from Assam, Burma, Siam, Indo-China and Yunnan. Low or medium altitude species do occur in Sumatra, Penang, the Malay Peninsula, Burma, Philippines, Siam and Indo-China; and this is true of many of the species of southern China, Formosa, and Japan. Within the tropics all species are characteristically those of the primary forest areas, whether growing at low or higher altitudes. They are, without exception, small shrubs to small trees, and many of the species are described in the collector's notes as being only one or two meters high.

The study has been a difficult one, not only because of the inherent difficulties that one encounters in any large genus in such a group as the Celastraceae, but also because many of the extant specimens are inadequate. This is either because they were originally poorly prepared, or because of the absence of mature flowers or mature fruits. Perhaps the most striking case of this kind is *Microtropis borneensis* Merr. & Freem., somewhat inadequately described in this paper, although no less than 34 herbarium sheets representing it were available for study from Mount Kinabalu; the collectors failed, in all this material, to select really good specimens for every one of the numerous flowering specimens examined was either too young (immature buds only) or too old (petals and stamens fallen).

We have frankly not been able to propose a strictly natural arrangement of the sixty-four recognized species, partly because of inadequate material, lacking mature flowers or mature fruits as the case may be, partly because of the apparent variability when one attempts to evaluate such characters as the number of floral parts, the number of ovary cells, presence or absence of a distinct disk, and the disk characters, such as its consistency, whether thin or thickened, truncate or lobed, prominent or obscure, and whether the stamens are attached to its edge (as is the case i most species), or just outside or inside its margin or, as is the case with the type species of *Microtropis*, *M. discolor* Wall., where the disk is obsolete, the filaments being attached near the base of the petals, slightly uniting and alternate wit them. In most cases the filaments are borne o the edge of the strictly truncate disk, occasionall slightly outside or even slightly inside its margin occasionally alternating with distinct lobes (*M* *submembranacea* Merr. & Freem.). The disk usually prominent, thin or thickened, but occasionally subobsolete or so obscure as to be diff cult to detect. In a few species what ma represent the disk is made up entirely of the fuse basal portions of the filaments.

If one elects to utilize the presence or absen of the disk as a basis of generic segregation o immediately encounters difficulties. *Microtrop* *discolor* Wallich, the type of the genus, has trace of a disk, and the closely allied *M. pall* Pierre falls in the same category. Otherwise t entirely different *Microtropis Scottii* Parkinso quite unlike any other species of the genus, a the equally different *M. tenuis* Symington a *M. valida* Ridley of the *Cymoso-paniculatae* seri would fall together as a distinctly unnatu group merely because they have one character common—no disk. If *Microtropis* were to interpreted as having no disk, which is true of t type species, and the numerous other spec having a distinct disk were transferred to *Pa* *celastrus*, *Otherodendron*, or *Chingithamnus*, t the logical procedure would be to set up a disti genus to take *Microtropis Scottii* Parkinson, a another genus to take *Microtropis tenuis* Symi ton and *M. valida* Ridley, in spite of the fact t the actual congeners of the last two species h a distinct disk, the series *Cymoso-paniculata*

Most species have strictly 5-merous flow but in six species only 4-merous ones were served. In *Microtropis Curranii* Merr., *M. f* *enensis* Dunn, *M. obscurinervia* Merr. & Fre and *M. Sakaguchiana* Koidz. 4- and 5-me flowers were found, even on the same branc

In *M. hexandra* Merr. & Freem. the stamens are usually six.

The number of ovary cells is often somewhat difficult to determine, partly because of the nature of some of the material available for study, partly because of the fact that in ten species only the fruits are known, and partly because, in some cases, the dividing wall may be only a partial one. Most of the species of which we have had adequate material have 2-celled ovaries, about fifteen have apparently 1-celled ovaries, and in about ten cases it has been impossible to determine this point. Three-celled ovaries have been credited to *Microtropis* by various authors, but none were observed in the numerous dissections made in the course of this study. We doubt if a 3-celled ovary is a proper character of *Microtropis*.

The fruit, although variable in shape and in size, seems to be reasonably constant in essential characters. The capsules may be merely apiculate, prominently rostrate or even long-beaked; small or relatively large; rather dry or somewhat fleshy. The pericarp may be longitudinally striate, smooth, or somewhat rugose, although it is usually glabrous, or in one species minutely subfurfuraceous-lepidotulate. Apparently all of them split down one side eventually exposing the solitary seed. Of about twenty species the fruits are still unknown.

The inflorescence is various. One series has strictly sessile axillary or lateral often many-flowered glomerules or fascicles, all flowers strictly sessile. In most cases the inflorescence is a strictly dichotomous cyme, forking regularly from one to several times, although at times it may be very greatly reduced. One apparently natural group is characterized by its paniculate-cymose inflorescences; i. e., the rachis is extended above the first pair of lateral branches, the few primary branches being racemosely arranged, the inflorescence hence essentially paniculate rather than dichotomous; but in two of the species placed in this group the disk is absent, although in the others it is well developed. As between those species with strictly sessile glomerules or fascicles and those with short- to long-peduncled dichotomous cymes, intermediates occur, it being sometimes rather difficult to determine whether a species should be placed in one category or in the other. Hence in the construction of the artificial key, we have in fourteen cases included the same species in two categories, and two cases in three categories. In some cases the cymes, still distinctly although shortly peduncled, may be reduced to three, two, or in one case to a single flower.

The vegetative characters show great variation in the shape, consistency, and size of the strictly opposite entire leaves, varying from membranaceous to rigidly coriaceous, from sessile to prominently petioled, and in size from a few cm. in length to as much as 30 cm., and in width from less than 1 cm. to as much as 15 cm. The nerves and reticulations, usually slender, may be raised or not, and vary from very prominent to nearly obsolete. Essentially all species are glabrous, exceptions occurring in *Microtropis gracilipes* Merr. & Freem. and in *M. confertiflora* Merr. & Freem., of China, where the younger parts and inflorescences may have a very few, widely scattered, short, stiff hairs. The sepal margins may be entire, erose, lacerate, ciliate or even pectinate, but their central portions are always more or less thickened and the marginal parts much thinner. In some cases the dried leaves are distinctly but minutely verruculose, and in such species the nerves and reticulations may be obsolete or subobsolete. Very frequently the tips of the terete, sulcate, slightly compressed or sharply 4-angled young branchlets show a characteristic pair of small aciculiform bodies that we interpret as incipient leaves, although in at least one case these were erroneously described as stipules; the latter are entirely absent.

In spite of the diversity in vegetative, inflorescence, floral, and fruit characters, one is impressed with the apparent naturalness of the group as a whole by the fact that no matter what the condition of the material may be—whether in fruit, in flower, in young bud, or even sterile, or whether the specimens be low or high altitude forms from any part of the generic range, one seldom fails to recognize a specimen at sight as representing *Microtropis* once one is reasonably familiar with a small series of species. The individual species, although by no means always readily distinguishable from each other, are not easily confused with the representatives of any other genus.

Not being able to devise any logical separation of numerous forms into sharply defined categories that might be classified as subgenera or sections, we have been content to indicate a number of series, bringing together groups of species that have certain more or less obvious characters in common. We do not claim that these are always natural groups, although two, *Ramiflorae* and *Cymoso-paniculatae*, are rather sharply defined and the indicated characters hold very closely. Some of the proposed series are admittedly highly artificial. Doubtless when good flowers and mature fruits of all the species are known, some more logical sequence and relationship of the various groups can be devised; but then doubtless many of the series herein proposed will be broken down and the species redistributed.

When this study was commenced it was intended to consider the few American species of the genus. Later it was learned that Dr. C. L. Lundell, of the University of Michigan, had assembled the available American material of *Microtropis*, with view to studying it. We accordingly submitted the small amount of New World material available to us to him for identification, and at the end of this paper merely list the known and excluded American species as a matter of record. As far as we have been able to determine, in spite of the discontinuous generic distribution, the few American species (other than those excluded from *Microtropis*) are congeneric with the Old World species as we have interpreted the genus, and in this respect Dr. Lundell is in agreement, after studying flowers representing a wide range of Old World forms. One may be at loss to explain the reasons for such wide gaps in continuous distribution as between the Indo-Malaysian and eastern Asiatic regions on the one hand and Mexico and Central America on the other hand, yet it seems to be an established fact that such discontinuous distributions do occur in a number of unrelated families such as the Juglandaceae, Araliaceae, and others. In any case the center of origin and distribution for *Microtropis* seems safely to be southern Asia if we may judge by the number and diversity of the species concerned.

This study has been prosecuted at the Arnold Arboretum at intervals during the past two years. It was based essentially on the material in the herbarium of the Arnold Arboretum, supplemented by important loans from a number of large herbaria in the United States, Europe and Asia, in most cases all available material being courteously loaned by the administrative officials. The abbreviations cited in the text are as follows, each indicating the particular herbarium involved:

A. Arnold Arboretum of Harvard University.
B. Botanical Gardens, Buitenzorg, Java.
C. Royal Botanic Gardens, Calcutta, India.
Ge. Jardin botanique, Geneva, Switzerland (includes material from the Garden Herbarium, de Candolle Herbarium, Boissier Herbarium, and Delessert Herbarium).
Gr. Gray Herbarium of Harvard University.
K. Royal Botanic Gardens, Kew, England.
L. Rijks Herbarium, Leiden, the Netherlands.
M. Philippine Bureau of Science, Manila, Philippines.
N. New York Botanical Garden, New York.
P. Principal Botanic Garden, Leningrad, U. S. S. R.
S. Botanic Garden, Singapore, Straits Settlements.
Su. Sun Yatsen University, Canton, China.
U. United States National Herbarium, Washington, D. C.
UC. University of California Herbarium, Berkeley, California.

In addition to this courteously loaned material, which has given us actual access to practically every extant type, or at least to practically every type collection, we are under obligations to Dr. R. Kanehira, Kyushu Imperial University, Fukuoka, Dr. T. Nakai, Tokyo Imperial University, Dr. G. Koidzumi of the Kyoto Imperial University, Japan, and to Sir Arthur Hill, Director of the Royal Botanic Gardens, Kew, England, for critical notes, photographs of historical material, and other data. We wish to express our sincere appreciation to all concerned who have thus placed at our disposal, important material without which this study, with such imperfections as it undoubtedly contains, would have been impossible. All species are represented in the Herbarium of the Arnold Arboretum, if not by actual specimens, then by photographs of types and other historical material.

Microtropis Wallich, List 152, no. 4337–40. 1830, *nomen nudum;* Meisn. Pl. Vasc. Gen. Tabl. Diagn. 68. 1837, Comment. 49. 1837, *descr.*, Arnott, Ann. Mag. Nat. Hist. **3**: 151. 1839 Endl. Gen. Pl. 1087. 1841; Walp. Repert. **1** 534. 1842; Lindl. Veg. Kingd. 588. 1847; Benth & Hook. f. Gen. Pl. **1**: 361. 1862; Laws. ir Hook, f. Fl. Brit. Ind. **1**: 613. 1875; Kurz, For Fl. Brit. Burma **1**: 250. 1877; Loesen. in Engl & Prantl, Nat. Pflanzenfam. **3** (5): 202. 1892 Trimen, Fl. Ceyl. **1**: 268. 1893; King, Jour. As Soc. Bengal **65** (2): 340. 1896 (Mater. Fl Malay. Penin. **2**: 626); Cooke, Fl. Bomba Presid. **1**: 229. 1902; Pitard in Lecomte, F Gén. Indo-Chine **1**: 879. 1912; Gamble, F Presid. Madras **1**: 205. 1918; Ridl. Fl. Mala

Penin. **1**: 443. 1922; Makino & Nemoto, Fl. Jap. ed. 2, 685. 1931; Lemée, Dict. Gen. Pl. Phan. **4**: 474. 1932; Kanj. & Das, Fl. Assam **1**: 267. 1937.

Paracelastrus Miq. Fl. Ind. Bat. **1** (2): 590. 1859; F. N. Williams, Bull. Herb. Boiss. II. **5**: 224. 1905.

Otherodendron Makino, Bot. Mag. Tokyo **23**: 60, *fig.* 1909; Makino & Tanaka, Man. Fl. Jap. 330. 1927; Makino & Nemoto, Fl. Jap. ed. 2, 686. 1931.

Chingithamnus Hand.-Maz. Sinensia **2**: 128, fig. 1932 (Chingithamnaceae, p. 126).

Because of the numerous technical descriptions of *Microtropis* that have been published it seems unnecessary or undesirable that a complete generic description be included in this paper, as it would merely repeat what is already known regarding the general characters of the group. As noted above we have been content to accept *Microtropis* Wallich as it has been interpreted by our numerous predecessors, and have not attempted to establish generic segregates or even subgenera. Variations in reference to the number of floral parts and ovary cells, inflorescences, absence or presence of the disk, and the disk characters, are briefly discussed above. We repeat that we have found no 3-celled ovaries in the material examined (a character that has been accredited to the genus by some authors), and that in one species 6-merous flowers were observed. In several species 4-merous and 5-merous flowers occur sometimes on the same specimen.

In the preparation of the following strictly artificial key we have utilized, for the most part, more or less obvious characters. It is probable that better results might have been attained for practical purposes of identification, had we elected to prepare a series of geographic keys, as Loesener[1] did, in part, in his treatment of the Aquifoliaceae, or as Sleumer[2] more recently did in his treatment of *Hydnocarpus*. For practical purposes of identification genera of the general type of *Ilex*, *Hydnocarpus*, and *Microtropis*, where the majority of the species are of strictly limited geographic distribution, geographic keys are often distinctly practicable. With *Microtropis* it would be a relatively simple matter to construct keys to the species of limited geographic areas, such as those of India, Burma, the Malaysian region, China, or the Philippines, with perhaps less duplication of entries than occurs in the following artificial key, for the reason that most of the known species of the genus are strictly local.

Artificial Key to the Species

1. Flowers in lateral, rarely terminal, sessile glomerules or fascicles.
  2. Leaves obtuse, rounded, or sometimes slightly retuse, never acuminate.
    3. Leaves 6–8 cm. long (India).....1. *M. ramiflora.*
    3. Leaves 2–5 cm. long.
      4. Leaves oblong or elliptic, slightly rugose on the upper surface when dry (Ceylon) 2. *M. zeylanica.*
      4. Leaves broadly elliptic to suborbicular, the upper surface smooth (Borneo) 3. *M. suborbiculata.*
  2. Leaves more or less acuminate or at least acute.
    3. Leaves three or more times as long as broad.
      4. Leaves 20–30 cm. long; fascicles cauline or on the larger branches below the leaves (Philippines)....................53. *M. fasciculata.*
      4. Leaves not exceeding 20 cm. in length, mostly 6–15 cm. long; fascicles axillary or terminal.
        5. Leaves verruculose; nerves obscure; reticulations obsolete or nearly so; leaves pale when dry (Hainan)...........7. *M. obscurinervia.*
        5. Leaves not verruculose; nerves distinct; reticulations evident, mostly more or less raised on one or both surfaces and often rather close.
          6. Leaves 15–20 cm. long, lower surface pale brown in stromg contrast to the darker upper surface; inflorescences terminal (Borneo) 40. *M. bicolor.*
          6. Leaves 7–15 cm. long, under surface usually paler than the upper one but not in striking contrast to it; inflorescences lateral.
            7. Inflorescences 2-flowered; leaves rather slenderly acuminate (Kwangtung) 18. *M. biflora.*
            7. Inflorescences more than 2-flowered; leaves acute to very shortly acuminate (Ceylon) 4. *M. Wallichiana.*
    3. Leaves mostly less than three times as long as broad.
      4. Leaves verruculose on the upper surface when dry.
        5. Flowers 4-merous (Yunnan) 10. *M. sessiliflora.*
        5. Flowers 5-merous.
          6. Leaves verruculose only on the upper surface, the nerves and reticulations distinct on the lower surface (India).......5. *M. Stocksii.*
          6. Leaves verruculose on both surfaces; nerves obscure.

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[1] **Loesener, T.** Monographia Aquifoliacearum. Nov. Act. Acad. Caes. Leopold.-Carol. Nat. Cur. **78**: i–viii. 1–598. *t. 1–15.* 1901; II. **89**: 1–313. 1908.

[2] **Sleumer, H.** Monographie der Gattung Hydnocarpus. Bot. Jahrb. **69**: 1–94. *t. 1–4.* 1938.

7. Leaf base broadly acute, rounded, or narrowly rounded-subtruncate; petioles not exceeding 5 mm. in length (Kwangsi) 9. *M. osmanthoides.*

7. Leaf base cuneate to decurrent-acuminate; petioles 0.5–1.5 cm. long.

8. Leaves elliptic to oblanceolate, 10–20 x 3–8 cm.; sepals fimbriate; fascicles few-flowered (Hainan)...7. *M. obscurinervia.*

8. Leaves oblong-elliptic, 4–8 x 1.5–4 cm.; sepals entire; fascicles few-flowered (Siam) 6. *M. crassifolia.*

8. Leaves elliptic to ovate, 8–17 x 3–12 cm.; sepals erose, not fimbriate; fascicles many-flowered (India). ....8. *M. latifolia.*

4. Leaves mostly smooth, or at least not verruculose when dry, the ultimate reticulations often more or less raised.

5. Flowers 3–4 mm. long, the petals about 3 mm. long.

6. Leaves 5–10 cm. long, elliptic, oblong-elliptic, or broadly oblong-lanceolate.

7. Leaves subacuminate, the secondary nerves faint, scarcely evident; fascicles few- (2–3) flowered.

8. Leaves thickly coriaceous, subacuminate, brownish olivaceous on the lower surface when dry; nerves obscure on the upper surface (Malay Peninsula) 37. *M. ophirensis.*

8. Leaves chartaceous, sharply acuminate, the lower surface pale when dry, the nerves slender, somewhat elevated on both surfaces; inflorescences strictly 2-flowered (Kwangtung) ....18. *M. biflora.*

7. Leaves subacute to obtuse, not acuminate; secondary nerves forming a conspicuous reticulum; cymes compact, subsessile, 3–8-flowered (Kwangtung-Lantao Island) 12. *M. reticulata.*

6. Leaves 8–15 cm. long, ovate to elliptic, mostly subabruptly and rather slenderly acuminate (Malay Peninsula, Sumatra) 35. *M. elliptica.*

5. Flowers 1.5–2.5 mm. long; leaves subacute to acuminate; primary nerves 8–12 pairs, slender but distinct, spreading (Ceylon) 4. *M. Wallichiana.*

1. Flowers in short- or long-peduncled, solitary or fascicled, few- to many-flowered (in a few cases the peduncles 1- or 2-flowered only), axillary or terminal, dichotomous cymes, or in cyme-like panicles, sometimes subcapitate-glomerate, but when so the short peduncles evident.

2. Leaves subsessile or with very short stout petioles, the bases very broadly rounded to abruptly obtuse, texture always rigidly coriaceous.

3. Leaves 6–12 cm. long; flowers not glomerate-capitate.

4. Leaves ovate, the base very broadly rounded; cymes up to 1 cm. long (Borneo) 39. *M. ovata.*

4. Leaves elliptic to oblong-elliptic, distinctly narrowed below to the abruptly obtuse, slightly rounded, or even slightly cordate base (Borneo) 38. *M. rigida.*

3. Leaves 2–5.5 cm. long; flowers in short-peduncled capitate glomerules (Ceylon) 2. *M. zeylanica.*

2. Leaves distinctly petioled, the base cuneate, acute, or decurrent-acuminate, very rarely rounded; texture various.

3. Inflorescences paniculate-cymose; i. e., the rachis normally produced above the first pair of lateral branches, the few primary branches racemosely arranged.

4. Inflorescences 5 to 6 times as long as the petioles (Malay Peninsula)............58. *M. valida.*

4. Inflorescences not more than twice, or rarely three times, as long as the petioles.

5. Leaves 5–9 x 2–4 cm., membranaceous or thinly chartaceous; disk none or very obscure (Malay Peninsula)...........57. *M. tenuis.*

5. Leaves much larger, mostly 10–22 x 4–12 cm.; disk evident, truncate.

6. Leaves rigidly and thickly coriaceous, the lateral nerves rather distinct above, obscure on the very pale, almost subverruculose lower surface (Borneo) 60. *M. sterrophylla.*

6. Leaves chartaceous to coriaceous (but not rigidly so), the lateral nerves fairly distinct on both surfaces.

7. Branchlets slender, about 1 mm. in diameter, prominently sulcate; leaves thinly chartaceous or the younger ones submembranaceous (Philippines)....62. *M. basilanensis.*

7. Branchlets rather stout, mostly 1.5–3 mm. in diameter, terete or at most slightly compressed, rarely somewhat sulcate; leaves chartaceous to coriaceous.

8. Leaves 3–4 times as long as broad.

9. Fruits about 2 cm. long, narrowed upward to the more or less rostrate apex; reticulations lax (Philippines) 63. *M. rostrata.*

9. Fruits about 1 cm. long, reticulations close (Borneo)........59a. *M. kinabaluensis.* var. *acuminata.*

8. Leaves less than 3 times as long as broad.

9. Leaves rather thinly chartaceous (Philippines)..................61. *M. rubra.*

9. Leaves coriaceous or firmly chartaceous.

10. Leaves pale in the lower surface; fruits unknown (probably about 1 cm. long) (Borneo).......59. *M. kinabaluensis*

10. Leaves brown or brownish beneath; fruits 1.5–2 cm. long (Philippines) 64. *M. platyphylla*

3. Inflorescences normally of strictly dichotomous cymes, the rachis never produced above the

first fork, simple, rarely 1- or 2-flowered, once to several times dichotomously branched, sometimes greatly reduced and almost fascicle-like; flowers few to many; peduncles very short to greatly elongated.

4. Leaves 16–30 cm. long (in some forms with smaller ones 12–15 cm. long on the same branches with the larger ones).

5. Leaves verruculose when dry (Burma). 44. *M. macrophylla.*

5. Leaves not verruculose.

6. Fruit oblong-ovoid, abruptly long caudate or stoutly rostrate.

7. Fruits abruptly long-caudate, the slender beak about 1 cm. long (Malay Peninsula) 51. *M. longirostris*

7. Fruit tapering more or less gradually into a stout beak 5 mm. long or less (Philippines) 52. *M. chartacea.*

6. Fruits (where known) subglobose, oblong, ovoid or obovoid, at most merely short-apiculate, not rostrate.

7. Cymes at anthesis less than 1 cm. long, including the short peduncle, at most once-branched; flowers few (Sumatra) 54. *M. pauciflora.*

7. Cymes at anthesis much larger, often long-peduncled, several times branched, usually many-flowered.

8. Peduncles stout, axillary, at most 2.5 cm. long, frequently much shorter; leaves chartaceous, usually elliptic; nerves 9–12 pairs (Sumatra)......55. *M. sumatrana.*

8. Peduncles slender, mostly terminal, about 3 cm. long; leaves oblong, mostly membranaceous; lateral nerves about 8 pairs (Malay Peninsula)..46. *M. peduncularis.*

8. Peduncles mostly lateral, slender, often filiform, mostly 3.5–8 cm. long; leaves oblong to oblong-elliptic; lateral nerves about 12 pairs; cymes usually lax, open.

9. Flowers small, about 3 mm. long; peduncles 4–8 cm. long (Malay Peninsula) 45. *M. filiformis.*

9. Flowers relatively large, 4.5–5 mm. long; peduncles 3–4.5 cm. long (Burma) 45a. *M. filiformis.* var. *grandiflora.*

4. Leaves normally less than 15 cm. long.

5. Leaves mostly not more than twice as long as wide.

6. Inflorescence at anthesis normally not exceeding the petioles in length.

7. Leaves verruculose when dry, coriaceous.

8. Leaves 1.5–4 cm. wide; lateral nerves about 8 pairs, obsolete or nearly so on the lower surface (Siam).........6. *M. crassifolia.*

8. Leaves 4–8 cm. wide; lateral nerves 4–5 pairs, more or less evident on the lower surface (Burma).......43. *M. longifolia.*

7. Leaves never verruculose when dry, texture various.

8. Leaves at most chartaceous.

9. Leaves caudate-acuminate, their petioles 1–1.5 cm. long (Java)..33. *M. javanica.*

9. Leaves bluntly or acutely acuminate, not caudate, their petioles less than 1 cm. long.

10. Leaves very broadly, obtusely, and bluntly acuminate, or merely obtuse, subglaucous beneath, nerves very prominent (Burma)....41. *M. Gagei.*

10. Leaves acutely acuminate.

11. Lateral nerves very slender, acumen very short (Formosa) 25. *M. micrantha.*

11. Lateral nerves conspicuous beneath, the usually rather slender acumen about 1 cm. long (Malay Peninsula, Sumatra)..........35. *M. elliptica.*

11. Leaves rigidly and thickly coriaceous, very abruptly short-acuminate (Borneo).........36. *M. borneensis.*

8. Leaves coriaceous.

9. Leaves obtuse or rounded; lateral nerves about 5 pairs (Hongkong, Hainan, Kwangsi)..........11. *M. paucinervia.*

9. Leaves more or less acuminate; nerves 6–8 pairs.

10. Leaf-tips usually glandular-indurated (Philippines).......16b. *M. Curranii* var. *zambalesensis.*

10. Leaf-tips not glandular-indurated (Kwangtung, Kwangsi) 13. *M. cathayensis.*

6. Inflorescences at anthesis distinctly longer than the petioles.

7. Inflorescences several times longer than the petioles.

8. Leaves coriaceous, obtuse (India) 15. *M. microcarpa.*

8. Leaves thinly chartaceous, acuminate (Burma)..........47a. *M. bivalvis* var. *laeta.*

7. Inflorescences normally more than one and one-half to two times as long as the petioles, their peduncles 5–10 mm. long.

8. Leaves chartaceous or submembranaceous, 1.5–2 cm. wide, green on both surfaces when dry; fruits merely apiculate; disk distinctly lobed (Hainan, Kwangtung) 26. *M. submembranacea.*

8. Leaves coriaceous; disk truncate.

9. Leaves mostly rounded or obtuse, rarely somewhat narrowed to the short, broad, and obtuse acumen which is never glandular-indurated; nerves ascending (Japan, Riu Kiu, Formosa) 31. *M. japonica.*

9. Leaves more or less acuminate or merely acute, often abruptly and bluntly short-

apiculate, the tip dark colored or black, glandular-indurated; nerves in general spreading (Philippines) 16. *M. Curranii.*

5. Leaves normally more than twice as long as wide.

6. Leaves obtuse, rounded, or slightly retuse (India)................15. *M. microcarpa.*

6. Leaves acute or acuminate.

7. Peduncles 1–8 cm. long.

8. Leaves verruculose when dry; nerves obscure (Burma)...........42. *M. pachyphylla.*

8. Leaves not verruculose when dry, mostly smooth; nerves visible at least on the lower surface.

9. Cymes open, mostly lax, 4–10 cm. long, their peduncles very slender, greatly elongated.

10. Cymes very open, few-flowered; primary and secondary branches slender, elongated, one very large sessile flower with reflexed petals in each fork, the ultimate branches with one sessile and two slenderly long-pedicelled flowers (Burma).................48. *M. Scottii.*

10. Cymes with numerous flowers on the ultimate branches, these usually crowded, all pedicels very short; petals never reflexed.

11. Flowers small, about 3 mm. long.

12. Leaves mostly 11–20 cm. long; lateral nerves 9–11 pairs; peduncles 4–8 cm. long (Malay Peninsula, Sumatra).............45. *M. filiformis.*

12. Leaves 8–11 cm. long; lateral nerves about 7 pairs; peduncles 2–5 cm. long (Burma)......47a. *M. bivalvis* var. *laeta.*

11. Flowers relatively large, 4.5–5 mm. long (Burma).....45a. *M. filiformis* var. *grandiflora.*

9. Cymes various, mostly not exceeding 3 cm. in length, or if longer than this, then the flowers usually subcapitately crowded.

10. Leaves rigidly coriaceous, 4–8 cm. long (Malay Peninsula) .37. *M. ophirensis.*

10. Leaves submembranaceous, chartaceous, or at most subcoriaceous, never rigidly coriaceous.

11. Cymes 3-flowered.

12. Leaves 13–15 x 3.5–5 cm. (Yunnan) 20. *M. Henryi.*

12. Leaves 8–13 x 2–4 cm. (Penang) 47. *M. bivalvis.*

12. Leaves 6–9 x 1.5–2 cm. (Szechuan) 19. *M. triflora.*

11. Cymes more than 3-flowered.

12. Cymes very lax, few- (not more than 5) flowered (Penang) 47. *M. bivalvis.*

12. Cymes rather dense, or if somewhat lax or open, then more than 5-flowered.

13. Flowers subcapitately crowded, the heads 1–2 cm. in diameter, the flowers 4.5–5 mm. long (Kwangtung, Kwangsi) 50. *M. confertiflora.*

13. Flowers not subcapitately crowded, not more than 3.5 mm. long, or if subcapitate the cymes 1 cm. in diameter or less.

14. Cymes less than 1 cm. in diameter, few-flowered, the peduncles slender, 1.5–3 cm. long (Kwangtung) 49. *M. gracilipes.*

14. Cymes open, rather lax, usually branched 3–4 times, 3–5 cm. in diameter.

15. Leaves mostly 9–16 x 4–7.5 cm.; fruits 2 cm. long; disk united to the petals; anthers about 1.3 mm. long (Indo-China) 34. *M. fallax.*

15. Leaves mostly 8–13 x 2.5–5 cm.; fruits 1.5 cm. long or less; disk free, truncate, the filaments attached just below its margin on the back; anthers less than 0.5 mm. long (Indo-China, Yunnan, Kwangsi)......27. *M. Petelotii*

6. Peduncles less than 1 cm. long.

7. Peduncles 1-flowered (Yunnan) 17. *M. oligantha.*

7. Peduncles 2- to many-flowered.

8. Leaves coriaceous.

9. Leaves verruculose when dry, pale; nerves obsolete or subobsolete (Siam) 6. *M. crassifolia.*

9. Leaves not verruculose when dry, smooth or at least with more or less raised reticulations; nerves in general distinct on one or both surfaces.

10. Leaves in general obtuse or rounded, and usually pale when dry.

11. Lateral nerves 8–10 pairs (Kwangtung-Lantao Isld.)......12. *M. reticulata.*

11. Lateral nerves 4–5 pairs at most.

12. Leaves oblong-oblanceolate, 2.5–5 x 0.5–1.5 cm.; flowers small (Riukiu) 32. *M. Sakaguchiana.*

12. Leaves in general elliptic-obovate, to oblong-obovate to subovate, 3.5–9 x 1.5–5 cm.; flowers large (Japan, Riukiu, Formosa).31. *M. japonica.*

10. Leaves more or less sharply acuminate, caudate-acuminate, or merely acute.

11. Nerves not distinctly raised on the upper surface, the reticulations there obsolete or subobsolete.

12. Leaves 4–8 x 1.5–3 cm., gradually short-acuminate, dark-olivaceous on both surfaces when dry (Malay Peninsula)......37. *M. ophirensis.*
12. Leaves 6–13 x 3–5 cm., abruptly short-acuminate, the lower surface castaneous when dry (Borneo) 36. *M. borneensis.*
11. Nerves and reticulations distinctly raised on both surfaces when dry.
12. Leaves slenderly subcaudate-acuminate, 10–13 cm. long; cymes 3-flowered (Kwangtung) 14. *M. obliquinervia.*
12. Leaves shortly acuminate, 5–11 cm. long; cymes mostly many-flowered (Kwangsi, Kwangtung) 13. *M. cathayensis.*
8. Leaves chartaceous or submembranaceous.
9. Peduncles very short, 2-flowered (Kwangtung)..................18. *M. biflora.*
9. Peduncles more than 2-flowered.
10. Flowers 4- or 5-merous.
11. Nerves curved-anastomosing very close to the margin (Burma) 41. *M. Gagei.*
11. Nerves arched-anastomosing rather distant from the margin.
12. Lateral nerves 3–4 pairs only, sharply ascending; leaves caudate-acuminate (Burma)....21. *M. Beddomei.*
12. Lateral nerves 5 or more pairs, spreading or ascending; leaves more or less acuminate, sometimes caudate or subcaudate.
13. Branchlets sharply 4-angled, or very prominently sulcate-angled.
14. Nerves spreading; leaves oblong-ovate to oblong-elliptic; cymes rather open, lax.
15. Leaves 9–12 x 3.5–5 cm. (Kwangsi)............24. *M. tetragona.*
15. Leaves 3.5–8 x 1.5–3 cm.; disk distinctly lobed (Hainan, Kwangtung) 26. *M. submembranacea.*
14. Nerves in general ascending; leaves mostly lanceolate; cymes dense; internodes short (1–2.5 cm.) (Formosa to Yunnan) 28. *M. fokienensis.*
13. Branchlets terete, somewhat compressed or sulcate, rarely slightly angled.
14. Leaves in general lanceolate, mostly 1–3.5 cm. wide (Formosa to Yunnan).....28. *M. fokienensis.*
14. Leaves in general oblong to oblong-elliptic or oblong-obovate, mostly 2.5–6 cm. wide.
15. Primary nerves 9–11 pairs (Indo-China).........30. *M. pallens.*
15. Primary nerves about 7 pairs or less.
16. Fruits about 1.5 cm. long, prominently rostrate-acuminate (Philippines) 56. *M. philippinensis*
16. Fruits at most apiculate.
17. Fruits smooth, brownish olivaceous, the pericarp subglaucous, their pedicels smooth, 3–4 mm. long; leaves 13–15 x 3.5–5 cm.; nerves 5–6 pairs, very laxly and conspicuously arched-anastomosing, prominently raised on the lower surface (Yunnan) 20. *M. Henryi.*
17. Fruits green, longitudinally striate, their very stout pedicels very rugose, at most 2 mm. long; leaves 6–10 x 2.5–4 cm.; nerves 7 pairs slightly raised; disk truncate (Indo-China) 23. *M. chlorocarpa.*
17. Fruits grayish, sub-furfuraceous-lepidulote and very slightly rugulose, not longitudinally striate, the very stout pedicels usually very short; leaves variable in size, 7–15 × 2–6 cm. usually prominently caudate-acuminate; nerves 5–6 pairs; disk none (Sikkim, Assam, Burma, Siam, Indo-China, Yunnan, ?Penang) 29. *M. discolor.*
11. Flowers 6-merous; leaves thin, 5–7 x 1.5–3 cm.; cymes 2–3-flowered (Yunnan).............22. *M. hexandra.*

Series Ramiflorae

Leaves mostly coriaceous, small or medium in size, the flowers all strictly sessile in often many flowered, sessile, axillary or extra-axillary glomerules or fascicles. Species of India, Ceylon, Burma, Siam, China, and Borneo.

1. **Microtropis ramiflora** Wight, Ic. **3** (3): 7. *t. 977.* 1845, Spicileg. Neilgherr. **1**: 40. *t. 48.* 1846; Drury, Ind. Fl. **1**: 230. 1864; Beddome, Fl. Sylv. **2**: Anal. *t. 9. f. 6.* 1871; Lawson in Hook. f. Fl. Brit. Ind. **1**: 613. 1875; Fyson, Fl. Nilgiri & Pulney Hilltops **1**: 79, **2**: *f. 61.* 1915; Gamble, Fl. Presid. Madras **1**: 207. 1918; Fyson, Fl. So. Ind. Hill Sta. **1**: 112, **2**: 86. 1932.

Paracelastrus ramiflorus F. N. Will. in Bull. Herb. Boiss. II. **5**: 224. 1905.

India: Nilgiri Mountains, *Cleghorn*, s. n., in 1857 (E); *Perrottet* s. n. (Ge, photo. A), *746* (Ge); Anamalai Mountains, *Fischer 3730* (C), *3561* (E); Ootacamund, *Cleghorn* s. n., in 1856 (E); Madura District, Pulney Mountains, *Anglade 67* (Ge, A); without locality, *Wight 449*, type collection (Gr, P, L, photo. A); prob. Nilgiri Mountains, *Gardner 2847*, in part[1] (Gr).

The Ceylon material currently referred to this species differs from the Indian plant and this we have segregated as *M. zelyanica*. Stapf has credited this species to Borneo (British North Borneo, Kinabalu, *Haviland 1110*), but because of its isolated range and distinctly smaller and more rounded leaves, which are smooth on the upper surface, we have considered this to represent a distinct species, *M. suborbiculata*. Sarawak, *Native collector 2780, 2869*, referred by Merrill to *Microtropis ramiflora* Wight have elongated inflorescences and certainly do not represent this species; the material is too scanty for certain identification.

2. **Microtropis zeylanica** sp. nov.

Microtropis ramiflora sensu Thwaites Enum. Pl. Zeyl. 72. 1864; Trimen, Syst. Cat. Fl. Ceyl. 18. 1885, Fl. Ceyl. **1**: 269. 1893, non Wight.

Frutex vel arbor parva, glabra, ramis teretibus, ramulis ultimis 1–2 mm. diametro, plus minusve angulatis vel sulcatis; foliis coriaceis, plerumque ellipticis, 2–5.5 cm. longis, 1.3–4 cm. latis, rotundatis vel obscure latissime obtuseque acuminatis, basi rotundatis vel raro late acutis, margine revolutis, in sicco olivaceis vel brunneo-olivaceis, supra minute verruculosis, subtus paullo pallidioribus, laevibus, nervis primariis utrinque 5–7, gracilibus, supra obscuris, subtus magis distinctioribus, arcuato-anastomosantibus, reticulis laxis; petiolo circiter 2 mm. longo; inflorescentiis axillaribus, glomeratis, ad 5 mm. diametro, glomerulis sessilibus vel subsessilibus vel distincte (ad 3 mm.) pedunculatis; floribus confertis, sessilibus, 5-meris, sepalis suborbicularibus, 1.5–2 mm. diametro, coriaceis, margine erosis, submembranaceis; petalis subobovatis, rotundatis, circiter 2 mm. diametro; staminibus brevibus, disci margini insertis; ovario anguste ovoideo, sursum angustato, 2-loculari.

Ceylon: *Thwaites, C. P. 1228* (C, Ge, Gr holotype, P), *148* (C, M, P, U), *Gardner 179* (N, photo. A).

Both of these Thwaites numbers impress one as being made up of two or more individual collections. The Ceylon form, long referred to *Microtropis ramiflora* Wight, although allied to that species, has more slender branchlets, less robust petioles, smaller leaves, up to 5 cm. long but more often only 3 cm. long and 2 cm. wide, smaller flowers, and often shortly peduncled capitate glomerules rather than strictly sessile ones.

3. **Microtropis suborbiculata** sp. nov.

Microtropis ramiflora sensu Stapf, Trans. Linn. Soc. II. Bot. **4**: 140. 1894; Merr. Jour. Straits Branch Roy. As. Soc. (Spec. No.) 354. 1921 (Enum. Born. Pl. 354), non Wight.

Frutex glaber, ramis rigidis, subteretibus, ramulis perspicue 4-angulatis, 1.5–2 mm. diametro, atro-brunneis, internodiis 1–1.5 cm. longis; foliis crasse coriaceis, inter minores, orbiculari-ovatis vel orbiculari-ellipticis interdum suborbicularis, utrinque latissime rotundatis, margine revolutis, 2–3.5 cm. longis, 1.5–3 cm. latis, supra laevibus, subnitidis, in sicco atro-olivaceis, subtus pallidioribus, brunneis, nervis primariis utrinque 6–8, gracilibus, supra obscurissimis, subtus distinctioribus, leviter elevatis, arcuato-anastomosantibus, reticulis paucis, laxis, obscuris; petiolo crasso, atro-brunneo, circiter 2 mm. longo; glomerulis axillaribus terminalibusque, paucifloris, ad 5 mm. diametro; floribus 5-meris, sessilibus vel brevissime pedicellatis; sepalis exterioribus circiter 1.5 mm. longis, 3 interioribus orbicularis, 2 mm. diametro, omnibus late rotundatis, subcoriaceis, brunneis, margine leviter erosis; petalis late ovatis rotundatis, sepala aequantibus; staminibus brevibus, disci margini insertis; ovario anguste ovoideo, 2-loculari.

Borneo: British North Borneo, Mount Kinabalu, *Haviland 1110*, type (K, photo. A), altitude about 2400 m.

In spite of the extensive botanical field work that has been prosecuted on Mount Kinabalu since Haviland's visit in 1892, no collector seems to have relocated this species. Its alliance is clearly with *Microtropis ramiflora* Wight, and it is even more closely allied to the Ceylon form, long placed under Wight's species, that we here recognize as specifically distinct under the binomial *Microtropis zeylanica.* The Mount Murud material (*Native collector 2870, Moulton 123, 124*) placed by Merrill under *M. ramiflora* Wight in 1921, cannot possibly represent this species as its cymes, with very immature flowers, are about 1 cm. long. It probably represents an undescribed species, but more adequate material is essential.

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[1] *Gardner 2847* includes two different species, *M. ramiflora* Wight in the Gray Herb.; *M. latifolia* Wight in the Torrey Herb., N. Y. Bot. Gard.

4. **Microtropis Wallichiana** Wight in Thwaites Enum. Pl. Zeyl. 71. 1858, Trimen Syst. Cat. Fl. Ceyl. 18. 1885; Lawson in Hook. f. Fl. Brit. Ind. **1**: 613. 1875; Trimen, Fl. Ceyl. **1**: 269, 1893; Gamble, Fl. Presid. Madras **1**: 206. 1918.

Paracelastrus Wallichianus F. N. Will. Bull. Herb. Boiss. II. **5**: 224. 1905.

CEYLON: *Thwaites 43* (A, Ge, Gr, C, M, N, U, photo. A); *Walker* s. n. (Gr); *Wight 582* (E); no collector or number, 5000 ft. ex herb. Kurz (C); no data (C).

The material included under *Thwaites 43* shows much variation, probably indicating that specimens from various sources were included under that number when the duplicates were arranged for distribution. With ample material it would not be at all surprising if *M. Wallichiana* as interpreted by Thwaites, Lawson, and Trimen, would be found to consist of more than one species. Gamble records this species from the Western Ghats and Travancore, India, but we have seen no material representing it from outside of Ceylon.

5. **Microtropis Stocksii** Gamble, Kew Bull. 132. 1916, Fl. Presid. Madras **1**: 206. 1918.

Microtropis latifolia sensu Cooke, Bombay Fl. **1**: 229. 1902, non Wight.

INDIA: Concan, *Stocks*, type collection (C, Gr. K, L, photo. A); Coimbatore, Paralan, *Barber 3971* (K); without locality, *Wight 447* (partly) (K, N, photo. A); Anamalai Mountains, *Barber 5418* (C), *Fischer 3569* (C), *Beddome 1281, 1279* (P); no locality or collector given (C).

Gamble was manifestly correct in separating this from *M. latifolia* with which it had been confused. *Wight 447*, on which *M. latifolia* Wight was based, is a mixture of two different species, *M. Stocksii* Gamble and true *M. latifolia* Wight. The former differs from *M. latifolia* in having its leaves verruculose only on the upper surface, the lower surface shining and prominently veined. Lawson first published a description of Wight's species and this surely applies largely, if not wholly, to the other part of *Wight 447*, the form with broad, obscurely nerved leaves which are verruculose on both surfaces. *Fischer 3569* has much larger leaves than any of the other cited specimens.

6. **Microtropis crassifolia** Craib, Kew Bull. 349. 1926, Fl. Siam. Enum. **1**: 280. 1926.

SIAM: Chantaburi, Chantabun, Kao Soi Dao, *Kerr 9665* (K holotype, UC, photo. A); Rachasina, Korat, Kao Lem, *Kerr 9923* (K) not seen; Kao Lem, *Korat* [Craib] *3552*, Dec. 27, 1920 (K, photo. A).

A species with the characteristically obscurely nerved, coriaceous, minutely verruculose leaves in these characters resembling *M. latifolia* Wight and *M. osmanthoides* Hand.-Maz., and manifestly allied to them. The flowers are 5-merous.

7. **Microtropis obscurinervia** sp. nov.

*Microtropis canthoides** Hand.-Maz. var. *insularis* Merr. & Chun. ex Tanaka & Odashima, Jour. Soc. Trop. Hort. **10**: 372. 1938 (Contr. Hort. Inst. Taihoku Univ. **24**: 372), *nomen nudum.*

Frutex glaber circiter 1 m. altus, ramis ramulisque rigidis, teretibus, atropurpureis vel purpureo-brunneis, ultimis 2 mm. diametro; foliis coriaceis, oblongis vel oblongo-ellipticis vel late oblongo-oblanceolatis, 10–20 cm. longis, 3–8 cm. latis, apice plerumque late obtuse vel acute breviter acuminatis, deorsum angustatis, basi acutis, margine plerumque leviter revolutis, in sicco utrinque pallidis vel supra pallide olivaceis, minute verruculosis; nervis primariis utrinque 8–11, obscuris, interdum subobsoletis, secundariis reticulisque plerumque obsoletis; petiolo pallido, 0.5–1 cm. longo, 2–3 mm. crasso; inflorescentiis paucifloris, glomeratis, axillaribus terminalibusque, vix 5 mm. diametro; bracteis pallidis, 1 mm. longis, margine subciliatis; floribus 5-meris, sepalis inaequalibus, 2 exterioribus late ovatis, 3 interioribus suborbicularibus vel obovatis, circiter 3 mm. longis et 2.4 mm. latis, omnibus late rotundatis, margine subfimbriatis; petalis oblongis, rotundatis, 3 mm. longis; staminibus disci margini insertis; ovario anguste ovoideo, 2-loculari; fructibus immaturis, viridibus, oblongo-cylindraceis, apiculatis, saltem 1.5 cm. longis, pericarpio striato.

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* This is a manifest error for *osmanthoides* as it was to certain specimens originally determined as *Microtropis latifolia* Wight that the trinomial *Microtropis osmanthoides* var. *insularis* Merr. & Chun was applied (as an herbarium name only); Handel-Mazzetti never published *Microtropis canthoides.*

CHINA: Hainan, Poting, *How 73125*, type (A), *73126* (A); Yaichow, *Liang 63269* (A, N); Ngai District, Namlung, *Wang 34004*, *34709* (A, N); Ding-on District, Mo-cheung, *Wang 36046* (A, N), in forested ravines and on slopes.

A species in the group with *M. latifolia* Wight and *M. osmanthoides* Hand.-Maz. differing from both in its inflorescence, flower, and vegetative characters.

8. **Microtropis latifolia** Wight ex Lawson in Hook. f. Fl. Brit. Ind. **1**: 613. 1875; Gamble, Fl. Presid. Madras **1**: 206. 1918; Fyson, Fl. Nilgiri Pulney Hilltops **3**: 24. 1920.

INDIA: Madras, Nilgiri Mountains, *Wight 447* (Gr, L, N in part, photo. A), Gamble *13465* (K); without locality, probably Nilgiri Mountains, *Gardner 2847* (N).

In accepting Wight's binomial and in first describing the species Lawson gives its range from the Concan to the Nilgiris. He cites as a synonym "? *M. longifolia*, Wall. Cat. 4339 in part," which we have not actually seen, though we have examined a drawing thereof, and recognize it as an entity distinct from Wight's species. This collection was made by Gomez in Tavoy.

Wight 447 is a mixture of two distinctly different species, the second form being that described as *Microtropis Stocksii* Gamble. Lawson may have based his short description on both forms, but we interpret the type of *M. latifolia* Wight as that part of *Wight 447* with the broader, very coriaceous and rugulose leaves, the latter character being mentioned in the description.

Microtropis latifolia is distinguished from *M. obscurinervia* Merr. & Freem. by its erose, not ciliate, membranaceous sepal-margins; from *M. osmanthoides* Hand.-Maz. by the cuneate, not subtruncate, leaf-bases and longer petioles; and from *M. Stocksii* Gamble by the leaves being verruculose on both surfaces.

9. **Microtropis osmanthoides** (Hand.-Maz.) Hand.-Maz. Sinensia **3**: 189. 1933.

Chingithamnus osmanthoides Hand.-Maz. op. cit. **2**: 128, *1 f.* 1932.

Microtropis latifolia sensu Dunn & Tutcher, Kew Bull. Add. Ser. **10**: 61. 1912, non Wight.

CHINA: Kwangsi: Seh-feng Dar Shan, *Ching 7990* (N, photo. & fragm. A), an isotype of *Chingithamnus osmanthoides* Hand.-Maz.; Shah Man Taai Shan, Shang-sze District, near the Kwangtung border, *Tsang 22390* (A) (May 26, 1933, fruits very immature), *24063* (A), *24130* (A); Hongkong, *Tutcher 4625* (A).

This Chinese form is very similar to the Indian *M. latifolia* Wight, and is actually distinguished only by certain more or less obscure characters, the most obvious difference being that of the leaf shape. Here the leaf-bases are broadly acute to rounded-subtruncate and the petiole usually does not exceed 5 mm. in length. In *M. latifolia* Wight they are cuneate and longer petioled. We retain the two as distinct partly because of discontinuous distribution, partly because of the above more or less tangible differences. This is the form that Handel-Mazzetti described not only as a new genus (*Chingithamnus*), but also as the type of a new family *Chingithamnaceae* (Sinensia **2**: 126–129. *1 f.* 1932), which, in the following year (Sinensia **3**: 189. 1933), he reduced to *Microtropis*. This seems clearly to be the form credited to Hongkong by Dunn and Tutcher, Kew Bull. Add. Ser. **10**: 61. 1912, as *Microtropis latifolia* Wight, and accordingly Wight's species should be removed from the list of Chinese species and in its place *Microtropis osmanthoides* Hand.-Maz. should be accredited to Kwangtung Province. As noted above it is indeed very closely related to *M. latifolia* Wight of India, as represented by the type collection of the latter species, *Wight 447*. In the Chinese species the flowers are fewer and less crowded, while the calyx-segments are not entire but have distinctly ciliate margins. In both species the texture and venation of the leaves is remarkably similar, the leaf-surfaces on both sides being pale and verruculose when dry.

10. **Microtropis sessiliflora** sp. nov.

Frutex magnus vel arbor parva ad 8 m. alta, ramis rubro-brunneis, teretibus, ramulis circiter 2 mm. diametro; foliis oblongo-lanceolatis, subellipticis, raro obovatis, coriaceis, distincte acuminatis, basi late acutis vel leviter decurrentibus, 9–13 cm. longis, 2.5–7 cm. latis, in sicco supra pallide olivaceis, obscure rugulosis, subtus paullo pallidioribus, nervis primariis utrinque circiter 7, distantibus, distinctis, subtus magis prominentibus, secundariis obscuris; petiolo 5 mm. longo, rugoso, 2 mm. crasso; glomerulis plerumque in axillis defoliatis, paucifloris vel multifloris, usque ad 5 mm. diametro; floribus omnibus sessilibus, parvis, 4-meris, bracteis inconspicuis; sepalis suborbicularibus, late rotundatis, 1 mm. diametro, margine membranaceis, erosis; petalis oblongo-ovatis, rotundatis, 2 mm. longis; filamentis brevissimis, margini disci insertis; ovario anguste ovoideo, sursum angustato, ut videtur 2-loculari; fructibus ellipsoideis, mucronatis, circiter 2 cm. longis et 1 cm. crassis, pericarpio laevi.

CHINA: Yunnan, Ping-Pien District, *Tsiang 13365*, type (Su, photo. A), a large shrub in forests; Wen-shan Hsien, *Tsai 51817* (A), a tree 25 feet high.

The alliance of this species is clearly with *M. latifolia* Wight. Among the known species of this group it is characterized by its 4-merous, small flowers crowded in rather inconspicuous glomerules chiefly in the axils of fallen leaves.

Series PAUCINERVIAE

Leaves small, coriaceous, obtuse, few-nerved, the flowers crowded in small, axillary, solitary, very shortly peduncled capitate cymes. China.

11. **Microtropis paucinervia** Merrill & Chun in herb. sp. nov.

Microtropis japonica sensu Merr. Sunyatsenia **1**: 197. 1934, non Hall. f.

Arbor parva, circiter 6 m. alta, glabra, ramis teretibus, ramulis ultimis distincte 4-angulatis, purpureo-brunneis, 1.2–2 mm. diametro; foliis coriaceis, elipticis vel oblongo-ellipticis vel obovatis, 3–5 cm. longis, 1.5–3 cm. latis, obtusis vel rotundatis, basi acutis, margine revolutis, sicco supra viridibus vel olivaceis, subrugosis, subtus pallidioribus, nervis primariis utrinque circiter 5, gracilibus, adscendentibus, arcuato-anastomosantibus, reticulis indistinctis, subtus cum costa nervisque paullo elevatis; petiolo 2–3 mm. longo, rugoso; inflorescentiis in axillis superioribus, brevibus, subsessilibus vel breviter pedunculatis, pedunculo sub fructu crasso, 2–3 mm. longo; floribus confertis, 5-meris, circiter 2.5 mm. longis, sepalis subcoriaceis, rubro-brunneis, rugosis circiter 1.5 mm. longis, subreniformibus, margine fimbriatis; petalis 5, anguste oblongo-obovatis, apice leviter lacerato-fimbriatis obtusis, 2.2 mm. longis, staminibus 5, filamentis brevibus, disci margini insertis; ovario 2-loculari; fructibus solitariis, crassis, oblongo-ellipsoideis, 1.5 cm. longis, circiter 8 mm. diametro, haud vel brevissime apiculatis, sepalis persistentibus crassis, exterioribus rugosis, glabris orbiculari-rotundatis, circiter 2.5 mm. latis, bracteolis parvis, quam sepala minoribus, crasse coriaceis, persistentibus.

CHINA: Hainan: Hing Lung, Po-Ting District, *How 73695* (A); Hongkong, *Chun 22999*, *40294*, type (Su, photo. & fragm. A), *40295* (Su, N); *Herb. Hongkong 1001* (M), distributed as *Ilex;* Kwangsi: Shap Man Taai Shan, Shang-sze District, *Tsang 22436* (A).

Among the small-leaved species this is characterized by its rounded or obtuse, few-nerved leaves, 4-angled branchlets, being somewhat similar to *M. japonica* Hall. f. but with shorter peduncled, almost subcapitate cymes, smaller flowers, and fimbriate sepals.

The binomial *Microtropis paucinervia* Merr. & Chun appears as a *nomen nudum* in Tanaka and Odashima, Jour. Soc. Trop. Hort. **10**: 372. 1938 (Contr. Hort. Inst. Taihoku Univ. **24**: 372), having been picked up by the latter authors from a named duplicate specimen.

Series RETICULATAE

Leaves small to medium, acute to acuminate, more or less reticulate on both surfaces, the nerves usually ascending, the flowers mostly few, in short axillary, solitary cymes. China.

12. **Microtropis reticulata** Dunn, Jour. Bot. **47**: 375. 1909, Jour. Linn. Soc. Bot. **39**: 469. 1911; Dunn & Tutcher, Kew Bull. Add. Ser. **10**: 61. 1912.

CHINA: Kwangtung, Lantao Island, *Dunn 6598* (K, photo. A).

This is the type collection and we have seen no specimens that exactly match it. The species somewhat remotely resembles *M. fokienensis* Dunn, but is distinguished by its reticulate leaves and more numerous primary lateral nerves, chiefly 10 to 12 on each side of the midrib (8–10 according to Dunn's description) as contrasted to about 6 more ascending ones in *M. fokienensis* Dunn, and its obtuse leaves. *Elaeodendron Fortunei* Turcz., mentioned by Dunn in the discussion following his description is *Euonymus Fortunei* (Turcz.) Hand-Maz.; see Rehder, Jour. Arnold Arb. **19**: 75. 1938 for an adjustment of the synonymy of the latter.

13. **Microtropis cathayensis** sp. nov.

Frutex glaber, 1–3 m. altus, ramis teretibus, plus minusve lenticellatis, ramulis 1.5–2 mm. diametro, teretibus vel obscure angulatis vel sulcatis, internodiis 2–3.5 cm. longis; foliis coriaceis, oblongo-ellipticis vel oblongis, 5–11 cm. longis, 1.5–4.5 cm. latis, utrinque subaequaliter angustatis, breviter subobtuse acuminatis, basi acutis, in sicco supra olivaceis, subnitidis, subtus paullo pallidioribus, nervis primariis utrinque 6–8, subadscendentibus, utrinque cum reticulis sublaxis leviter elevatis; petiolo 0.5–1 cm. longo; cymis axillaribus, solitariis, ad 1 cm. longis, breviter crasseque pedunculatis, simplicibus, densifloris, brevissime dichotome ramosis, ramis primariis vix 2 mm. longis, plerumque 3–4-floris; floribus omnibus sessilibus, confertis, 5-meris, circiter 3 mm. longis; bracteolis late ovatis, circiter 1 mm. longis; sepalis suborbicularibus, circiter 2 mm. diametro, interioribus tenuioribus, margine perspicue fimbriatis; petalis oblongo-ellipticis vel anguste oblongo-obovatis, rotundatis, 3 mm. longis; filamentis 1 mm. longis, disci margini insertis, antheris ovoideis, 0.5 mm. longis; ovario conico, obscurissime sulcato, vix 1 mm. longo, 2-loculari; capsulis oblongo-ellipsoideis vel deorsum leviter angustatis, brevissime apiculatis, 1–1.5 cm. longis, circiter 6 mm. diametro, pericarpio obscure longitudinaliter striato.

China: Kwangsi, Shaap Man Taai Shan, near Shang-sze, Kwangtung border, *W. T. Tsang 24771* (type, A), Nov. 28, 1934, a 4 foot shrub in thickets, *Tsang 24783* (A), a shrub 8 ft. high, in fruit; Yao Shan, Tseung District, *C. Wang 40215* (A); Kwangtung, Yeung Shan, *S. P. Ko 51007* (Su), a small tree in woods.

A species suggesting *Microtropis reticulata* Dunn, and probably as closely allied to that species as any other described form. Its coriaceous, more or less reticulate larger leaves, the somewhat ascending lateral nerves which are more prominent on the upper than on the lower surface, its shortly peduncled, densely flowered cymes, and the prominently fimbriate inner sepals are characteristic.

14. **Microtropis obliquinervia** sp. nov.

Frutex glaber, ramulis nitidis, teretibus vel novellis leviter compressis, 2 mm. diametro, internodiis 1–3 cm. longis; foliis oblongo-lanceolatis, coriaceis, tenuiter acute acuminatis, basi cuneatis vel decurrentibus, nitidis, supra olivaceis, subtus brunneis, 10–13 cm. longis, 3–4 cm. latis, nervis primariis utrinque 7, obliquis, utrinque distinctis, secundariis laxe reticulatis; petiolo circiter 5 mm. longo, 2 mm. crasso; cymis simplicibus, brevibus, axillaribus, 3-floris, 5 mm. longis; bracteis circiter 1.5 mm. longis latisque, apiculatis, margine submembranaceis; floribus 5-meris, sepalis reniformibus, subcoriaceis, circiter 1 mm. longis, 3 mm. latis, minute erosis; petalis late oblongis, submembranaceis; staminibus 5, disci margini insertis; ovario subpyramidato, 1-loculari.

China: Kwangtung, Lok-cheong District, *Chun 42514* (A) type, *42515* (A), a shrub; flowers white.

This is manifestly related to *Microtropis cathayensis* Merr. & Freem., differing in its longer, slenderly and sharply acuminate leaves and few-flowered inflorescences. An imperfect fruiting specimen, *Chun 22727* (Su) from San Kong, Lin District, Kwangtung, probably belongs here. The fruits are apparently about 1 cm. long, and more or less ellipsoid; the pericarp is fallen.

Series Microcarpae

Leaves small, coriaceous, mostly rounded or obtuse; cymes dichotomous, elongated or in one species, rather short. India, Ceylon, Luzon.

15. **Microtropis microcarpa** Wight, Ic. **3** (3): 7. *t. 975.* 1845, Spicileg. Neilgherr. **1**: 40. *t. 46.* 1846; Lawson in Hook. f. Fl. Brit. Ind. **1**: 614. 1875; Cooke, Fl. Bombay **1**: 229. 1902; Fyson, Fl. Nilgiri Pulney Hilltops **1**: 80. 1915; Gamble, Fl. Presid. Madras **1**: 207. 1918.

Elaeodendrum (?) *nilghirense* Wall.[1] List no. 4409 (p. 250) 1832, *nomen nudum.*

Microtropis ovalifolia Wight, Ic. **3** (3): 7. *t. 976.* 1845, Spicileg. Neilgherr. **1**: 40. *t. 47.* 1846; Lawson, l. c.; Gamble, l. c.

Paracelastrus microcarpus F. N. Will. Bull. Herb. Boiss. II. **5**: 224. 1905.

Paracelastrus ovalifolius F. N. Will. l. c.

India: Nilgiri Mountains, *Wight 471* (Gr, L, N, P, photo. A, type collection of *M. microcarpa* Wight), *Wight 448* (C, Gr, K, L, N, P, type collection of *M. ovalifolia* Wight), *Clarke 11452* (P), *Wilson* s. n. (A), *Hooker f. & Thomson* (Ge, L), *Fischer 3932, 4592* (C), *Gouch* (E), *Cleghorn* (E), no collector (E), *Hohenacker 1451* (A, Ge, L, P), *Perrottet* s. n. (Ge), *751* (P).

This is a reasonably uniform species apparently confined to the Nilgiri Mountains in southern India. In describing what he took to be two distinct species in 1845, Wight states: "These two are very nearly allied species, but I think them quite distinct." Lawson and Gamble accepted Wight's conclusions and retained the two as distinct, crediting the distinguishing characters to Wight. Fyson in 1915 was able to separate them only on the distinctly unsafe basis of fruit color. In 1846 Wight recognized a third species, *Microtropis densiflora* Wight, with somewhat larger leaves than the other two that he recognized. With abundant material now available for study, and merely allowing slight variation within the species, we are constrained to reduce the *M. ovalifolia* Wight to *M. microcarpa* Wight, and for the present place *M. densiflora* Wight as the following variety:

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[1] Wallich 4409, *Gordonia* ? *peduncularis* Wall. List p. 155. 1830 is a Penang specimen representing *Ixonanthes icosandra* Jack. On page 250, in the corrections, this number is reassigned to *Elaeodendrum* ? *nilghirense* Wall., based on specimens from the Nilgiri Mountains collected by Nolan and by Wight; this is *Microtropis microcarpa* Wight.

15a. **Microtropis microcarpa** Wight var. **densiflora** (Wight) comb. nov.

Microtropis densiflora Wight, Ic. **3** (3): 7. *t. 976.* 1845, Spicileg. Neilgherr. **1**: 40. *t. 47.* 1846; Lawson in Hook. f. Fl. Brit. Ind. **1**: 614. 1875; Gamble, Fl. Presid. Madras **1**: 207. 1918.

Paracelastrus densiflorus F. N. Will. Bull. Herb. Boiss. II. **5**: 224. 1905.

INDIA: Nilgiri Mountains, *Wight 470*, type collection (Ge, Gr, L, P, photo. A), *Gardner* (M, N).

This has been consistently recognized as a distinct species by all botanists who have considered it since Wight described and illustrated it in 1845, which we suspect to be due more to the weight of authority than to any constant differential characters. It differs from *M. microcarpa* Wight in its leaves averaging somewhat larger than in the latter species, but some typical specimens of *M. microcarpa* have leaves as large as are those of *M. densiflora* Wight. Another differential character is its shorter inflorescences, but here again some specimens of *M. microcarpa* Wight match *M. densiflora* Wight in inflorescence-length, while on the same specimens other inflorescences are the typical elongated ones of the former species. We strongly suspect that what we here recognize as a variety will eventually be relegated to the synonymy of *M. microcarpa* Wight.

16. **Microtropis Curranii** Merr. Philip. Jour. Sci. Bot. **3**: 238. 1908, Enum. Philip. Fl. Pl. **2**: 482. 1923.

PHILIPPINES: Luzon, Benguet Province, *Curran 4966* (U), *4970* (M, photo. A), *10846* (U), *Leaño 25135* (U), *25133* (A, M), *Sandkuhl 231* (M), *Merritt 14182* (M), *Williams 1300* (A, N, U), *Ramos 5731*, *5706* (L, M).

This species grows in the mossy forest on Mount Tonglon (Santo Tomas) and on Mount Ugo at approximately 2500 m. altitude. Even as here interpreted two trends are more or less evident, the typical form with smaller, dark-colored leaves and short dark-colored cymes, and the other with somewhat larger, paler leaves, and paler slightly longer peduncled inflorescences (*Williams 1300, Curran 10834*). In some of the cited specimens both 4-merous and 5-merous ones occur on the same plant, although in the original description only 4-merous flowers were noted. Superficially the species most closely resembles the Indian *Microtropis microcarpa* Wight, but has much shorter inflorescences. One character, not hitherto noted, and this applies to the two varieties here recognized, is the peculiar indurated-glandular leaf-tips.

16a. **Microtropis Curranii** Merr. var. **zambalesensis** var. nov.

A typo differt internodiis brevioribus, foliis crassioribus utrinque magis attenuatis distincte acuminatis, cymis brevioribus.

PHILIPPINES: Luzon, Zambales Province, *Ramos 4698* (M, U, photo. A), *5026* (M, U), Curran & Merritt 8071 (M, U).

A high altitude form growing on the Zambales range at an altitude of about 1500 m. This form is less distinct from the type than is the following one.

16b. **Microtropis Curranii** Merr. var. **obovata** var. nov.

A typo differt foliis magis coriaceis, paullo majoribus, obovatis vel oblongo-obovatis, basi decurrentibus, ad 6 cm. longis et 5 cm. latis, apice abrupte breviterque obtuse apiculatis, apiculis valde glanduloso-induratis, petiolo paullo longiore.

PHILIPPINES: Luzon, Rizal Province, Mount Lumutan, *Ramos 42238*, April, 1923 (M, Ge, Su, photo. A). A 2 m. high shrub in the mossy forest at 1200 m. altitude.

The material available is rather poorly prepared, the three specimens examined having only immature flowers, and even these, and the inflorescences, not in good condition. For the present, at least, it seems best placed as a variety of *Microtropis Curranii* Merr., rather than to be characterized as a distinct species. As noted above the species and the two varieties here segregated are characterized by the dark colored or black leaf tips which are indurated-glandular.

Series OLIGANTHAE

Leaves small to medium, mostly rather thin; cymes greatly reduced, 1-, 2-, or 3-flowered; flowers 5-merous. China, Burma.

17. **Microtropis oligantha** sp. nov.

Microtropis discolor sensu Dunn, Jour. Linn. Soc. Bot. **39**: 469. 1911, non Wall.

Frutex circiter 1.2 m. altus, glaber, ramis teretibus, purpureo-brunneis, ramulis ultimis 1.5–2 mm. diametro, obscure angulatis vel sulcatis, internodiis 3–10 cm. longis; foliis oblongo-ellipticis, chartaceis, in sicco pallide olivaceis, subtus pallidioribus, subopacis vel obscure nitidis, distincte acuminatis, basi late acutis, nervis primariis utrinque circiter 8, gracilibus, haud perspicuis, arcuato-anastomosantibus, quam secundarii reticulisque sublaxis vix distinctioribus; petiolo 1.5 cm. longo; inflorescentiis axillaribus et in axillis defoliatis, solitariis vel depauperato-fasciculatis, pedunculo circiter 0.5 mm. longo, 1–3-floris; floribus 5-meris, sepalis suborbicularis vel subreniformibus, late rotundatis, subchartaceis, 1.5–2 mm. longis; petalis oblongo-ellipticis vel ellipticis, circiter 3.5 mm. longis, 1.5–1.8 mm. latis; filamentis disci margini insertis, 1 mm. longis, antheris ellipsoideis, 0.5 mm. longis; ovario anguste ovoideo, 2-loculari; bracteolis binis, oblongo-ovatis, acutis vel acuminatis, 2 mm. longis.

CHINA: Yunnan, Fen Chen Lin Peak, alt. about 2500 m., *Henry 10851* (A holotype, N, Su), indicated as a shrub about 4 feet high, flowers white, the label on one of the sheets examined bearing merely the note "South of Red River."

Dunn enumerated this as representing *Microtropis discolor* Wall., which it resembles only rather superficially, and to which it is not closely allied because of the presence of a distinct disk. Wallich's species always has peduncled cymose inflorescences. This Chinese form is characterized by having 1- or at most 3-flowered peduncles, the entire inflorescence being less than half as long as the petioles.

18. **Microtropis biflora** sp. nov.

Frutex glaber, circiter 1.5 m. altus, ramis pallidis, teretibus, ramulis plerumque 1 mm. diametro, obscure angulatis vel sulcatis, internodiis 4–7 cm. longis; foliis oblongo-ellipticis vel late oblongo-lanceolatis chartaceis, in sicco utrinque subcinereo-viridibus vel pallide olivaceo-viridibus, nitidis, subtus paullo pallidioribus, 8–10 cm. longis, 2–3.5 cm. latis, graciliter acute acuminatis, basi cuneatis; nervis primariis utrinque 7–9, gracilibus utrinque leviter elevatis, arcuato-anastomosantibus, reticulis sublaxis, leviter elevatis; petiolo circiter 3 mm. longo; inflorescentiis axillaribus, brevissime (1–2 mm.) pedunculatis vel subsessilibus, 2-floris, sub anthesin petiolum subaequantibus; floribus 5-meris, sessilibus vel subsessilibus, bracteis ovatis, acutis, 1 mm. longis; sepalis late ovatis vel subreniformibus, subrugosis, margine membranaceis, obscure ciliatis, circiter 1 mm. longis; petalis oblongo-ellipticis, rotundatis, 3 mm. longis; staminibus circiter 1 mm. longis, filamentis gracilibus, disci margini insertis; ovario ovoideo, 2-loculari; fructibus oblongo-ellipsoideis, utrinque angustatis, leviter apiculatis, 12–14 mm. longis, circiter 6 mm. diametro, pericarpio longitudinaliter striato.

CHINA: Kwangtung, Loh Fau Shan, *S. P. Ko 52476*, December 12, 1932, a shrub in forests, flowers yellowish white (A, holotype), *Y. Tsiang 1696* (Su, UC), December 23, 1928, an undershrub 1.5 m. high, altitude about 250 m. in forests.

This species is essentially characterized by its very short, subsessile or shortly peduncled, 2-flowered inflorescences.

19. **Microtropis triflora** sp. nov.

Microtropis fokienensis Dunn, var. *longipedunculata* Cheng, Contr. Biol. Lab. Sci. Soc. China **9**: 199. 1934.

Frutex circiter 4 m. altus, glaber, ramis ramulisque teretibus vel ramulis obscure angulatis, obscure lenticellatis, brunneo-purpureis, ultimis 1 mm. diametro, internodiis 2–3 cm. longis; foliis lanceolatis vel oblongo-lanceolatis, 6–9 cm. longis, 1.5–2 cm. latis, in sicco olivaceo-viridibus, supra nitidis, subtus paullo pallidioribus, chartaceis, utrinque subaequaliter angustatis, graciliter acuminatis, basi cuneatis vel decurrentibus; nervis primariis utrinque 6, gracilibus, obscuris, subadscendentibus, obscure anastomosantibus, laxe reticulatis; petiolo circiter 1 cm. longo, pallido; cymis simplicibus, axillaribus, solitariis, trichotomis, 3-floris, circiter 1.5 cm. longis, flore centrali sessili, 2 lateralibus breviter (1–2 mm.) pedicellatis, pedunculo gracili, 1 cm. longo; floribus 5-meris, sepalis persistentibus orbiculari-ovatis, circiter 1.5 mm. longis; fructibus oblongo-

ellipsoideis vel anguste ellipsoideo-obovoideis, 1.4 cm. longis, deorsum angustatis, apice breviter apiculato-acuminatis, pericarpio laevi.

CHINA: Szechuan, Nanchuan-hsien, *Fang 5756* (A, N, Su), a shrub in thickets.

Rehder, Jour. Arnold Arb. **11**: 165. 1930, referred this collection to *M. fokienensis* Dunn, and whether considered as a variety, as Cheng proposed four years later, or as a species, as we propose, its alliance with *M. fokienensis* Dunn is close. It differs not only in the longer peduncles but also in its 3-flowered cymes. Normally Cheng's varietal name would be accepted in changing the status of this form from a variety to a species. It was abandoned because various other species of the genus have very much longer peduncles than does this Szechuan form.

Wang 35276, 35652, 36559 from Hainan, referred by Rehder, Jour. Arnold Arb. **18**: 216. 1937, to *M. fokienensis* Dunn. var. *longipedunculata* Cheng, we place under *Microtropis submembranacea* Merr. & Freem.

20. **Microtropis Henryi** sp. nov.

Frutex glaber, 2–2.5 m. altus, ramis teretibus, internodiis 2–4 cm. longis, ramulis 1.5–2 mm. diametro, sursum subangulatis; foliis oblongis vel oblongo-ellipticis, submembranaceis, laevibus, utrinque subaequaliter angustatis, distincte acuminatis, basi acutis, plus minusve decurrentibus, 13–15 cm. longis, 3.5–5 cm. latis, in sicco pallide olivaceo-viridibus, supra subnitidis, subtus paullo pallidioribus, nervis primariis utrinque 5 vel 6, gracilibus, curvato-adscendentibus, distantibus, laxe arcuato-anastomosantibus, supra subobscuris, subtus elevatis, distinctis, reticulis laxis, haud perspicuis; petiolo circiter 1 cm. longo; inflorescentiis cymosis, ut videtur paucifloris, in axillis defoliatis vel supra-axillaribus, simplicibus, pedunculo sub fructu 8–12 mm. longo, fructu centrali sessili, duobus lateralibus in ramulis patulis 3–4 mm. longis; sepalis persistentibus 4, pallidis, ovatis, circiter 1.5 mm. longis; fructibus pallide subolivaceis, laevibus, subglaucis, oblongo-ellipsoideis, brevissime apiculatis, circiter 13 mm. longis, pericarpio haud striato; pedunculo 6–12 mm. longo.

CHINA: Yunnan, Mengtze, *Henry 11443* (N, K holotype, photo. A); Ho-kou, *Tsai 52629* (A), the latter a shrub 7 ft. high, in forests, alt. about 500 m. The Henry number, on the Kew label, is indicated as a 6 ft. shrub in forests at 5000 ft. alt., while the sheet in the N. Y. Botanical Garden herbarium (actually Henry's native collector) bears the annotation "old wood, shrub 7–8′, not a climber, Dec. 16 (Ho)."

This in general resembles some forms of *Microtropis bivalvis* Wall., but has 4-merous flowers, shorter peduncles, the cymes (judging from the fruiting specimens) simple, bearing two lateral branches, each with a single smooth glabrous fruit, with a sessile terminal one between the spreading lateral branches. The leaves are somewhat larger than are most of those in Wallich's species and are thinner in texture.

21. **Microtropis Beddomei** sp. nov.

Frutex vel arbor parva, glabra, ramis pallidis laevibus, ramulis gracilibus, rubro-brunneis, teretibus vel novellis plus minusve compressis, 1 mm. crassis; foliis late oblongo-lanceolatis, sursum angustatis, perspicue caudato-acuminatis, acumine circiter 1.5 cm. longo, subobtuso, basi cuneatis, 6–7 cm. longis, 2–3 cm. latis, chartaceis, utrinque viridibus; nervis primariis utrinque 3–4, valde adscendentibus, quam secundarii magis distinctioribus; petiolo 5 mm. longo; cymis axillaribus vel extra-axillaribus, brevibus, 3-floris, glomeratis, vel brevissime (1–2 mm.) pedunculatis, 2–3 mm. diametro; floribus parvis, 4-meris, sessilibus, vix 2 mm. diametro; bracteis pallidis, 2 mm. longis; sepalis subreniformibus, circiter 1 mm. longis, 1.5 mm. latis, late rotundatis, submembranaceis; petalis oblongo-ovatis, 1.5 mm. longis, 1 mm. latis, rotundatis; staminibus disci margini insertis; ovario late ovoideo, 1 mm. longo, 2-loculari.

BURMA: Tenasserim, *R. H. Beddome 1274* ex herb. Mus. Brit. (P, photo. A), without further data.

Strongly characterized by its oblong-lanceolate, caudate-acuminate, few nerved leaves and its sharply ascending primary nerves. The sessile or very shortly peduncled cymes are all 3-flowered, flowers all sessile. The vegetative characters resemble some forms of *Microtropis fokienensis* Dunn, but the two species are not very closely allied.

Series HEXANDRAE

Similar to the preceding series but the stamens usually 6. China.

22. **Microtropis hexandra** sp. nov.

Frutex glaber, circiter 3 m. altus, ramis ramulisque gracilibus, ramis teretibus, ramulis plus minusve 4-angulatis, ultimis vix 1 mm. diametro; foliis oblongo-ellipticis, chartaceis vel junioribus submembranaceis, in sicco supra olivaceis, subtus pallidioribus, utrinque subnitidis, 5–7 cm. longis, 1.5–3 cm. latis, utrinque subaequaliter angustatis, apice leviter acuminatis, acumine acuto vel subobtuso, basi acutis; nervis primariis utrinque circiter 7, gracilibus, arcuato-anastomosantibus, subtus cum secundariis reticulisque sublaxis leviter elevatis, haud conspicuis; petiolo 5–8 mm. longo, canaliculato; cymis simplicibus, axillaribus extra-axillaribusque, vix 1 cm. longis, bifloris vel rariter trifloris, pedicellis 1–2 mm. longis, apice bibracteolatis, bracteolis ovatis, acutis, circiter 1 mm. longis; pedunculo 5–6 mm. longo; floribus albidis, 5–6-meris, circiter 3.5 mm. longis; sepalis 5, orbiculari-ovatis vel subreniformibus, late rotundatis, circiter 1.5 mm. longis, ad 2 mm. latis; petalis 6 (raro 5), oblongo-ellipticis vel anguste oblongo-obovatis, apice rotundatis, 3 mm. longis; staminibus 6 (raro 5), antheris ellipsoideis, 0.8 mm. longis, filamentis latis, tenuibus, quam antherae brevioribus, disci tenui margini insertis; ovario ovoideo-ellipsoideo, 1.3 mm. longo, 2-loculari.

CHINA: Yunnan, Ping-pien Hsien, *H. T. Tsai 60498* (type, A), June 29, 1934, a shrub in ravines, altitude about 1400 m.

A species superficially resembling *Microtropis discolor* Wall. characterized by its smaller leaves, 2-, rarely 3-flowered, simple short cymes, and in its usually 6-merous flowers. The thin, broad, short filaments are attached to the margin of an equally thin disk. The sepals are usually 5, the petals and stamens usually 6, rarely 5. Most of the cymes are 2-flowered, both flowers shortly pedicelled, but when 3-flowered, the central flower is sessile and the two lateral ones pedicelled.

Series CHLOROCARPAE

Leaves mostly rather small, acuminate; cymes dense or rather open, few- to rather many-flowered; fruits, where known, often green, the pericarp usually longitudinally striate (Formosa, China, Hainan, Indo-China).

23. **Microtropis chlorocarpa** sp. nov.

Frutex glaber, ramis teretibus, plerumque purpureo-brunneis, ramulis subangulatis vel sulcatis, ultimis 1–1.5 mm. diametro, internodiis 2.5–4 cm. longis; foliis oblongo-ellipticis vel oblongis, chartaceis, 6–10 cm. longis, 2.5–4 cm. latis, utrinque subaequaliter angustatis, distincte acuminatis, basi acutis, in sicco viridibus, subtus paullo pallidioribus; nervis primariis utrinque circiter 7, gracilibus, haud perspicuis sed utrinque leviter elevatis, arcuato-anastomosantibus, reticulis sublaxis; petiolo 8–10 mm. longo; cymis axillaribus, solitariis, breviter pedunculatis, paucifloris, sub fructu circiter 2.5 cm. longis, dichotomis, ramis primariis brevissimis, crassis, circiter 3 mm. longis, 2 mm. diametro, singulis bifloris, pedicellis rugosis, sub fructu brevissimis, crassis, circiter 2 mm. longis et 1 mm. diametro; pedunculo 8 mm. longo; bracteis late triangulari-ovatis, obtusis, circiter 1 mm. longis, bracteolis paullo minoribus; sepalis persistentibus 5, reniformi-ovatis, late rotundatis, circiter 1.5 cm. longis, 2.2 mm. latis, margine submembranaceis; capsulis oblongis, subcylindraceis, 1.2–1.4 cm. longis, apiculatis, pericarpio in sicco atro-viridi, longitudinaliter striato.

INDO-CHINA: Annam, Mount Bana, *J. & M. S. Clemens 4312* (A holotype, N), July 22, 1927, a shrub or small tree near the summit, altitude probably about 1200 m.

A species essentially characterized by its rather slenderly peduncled few-flowered cymes, with the two short thick lateral branches each bearing two very shortly pedicelled capsules, the pedicels rugose, thick, at most 2 mm. long. The nearly mature fruit is dark green when dry, the pericarp being somewhat longitudinally striate. The specimens were distributed as *Microtropis pallens* Pierre, but this form is remote from that species.

24. **Microtropis tetragona** sp. nov.

Frutex parvus, glaber, ramis teretibus, distincte lenticellatis, brunneis, ramulis ultimis acute 4-angulatis, purpureo-brunneis, 1.5–2 mm. diametro, internodiis 3–4 cm. longis; foliis chartaceis vel submembranaceis, oblongo-ellipticis, in sicco viridibus vel olivaceo-viridibus, subtus paullo pallidioribus, 9–13 cm. longis, 3.5–5 cm. latis, perspicue obtuse subfalcato-acuminatis, acumine circiter 1.5 cm. longo, basi late acutis; nervis primariis utrinque 6–8, gracilibus, subpatulis, laxe arcuato-anastomosantibus, utrinque distinctis, paullo elevatis, reticulis primariis sublaxis; petiolo pallido, rugoso, 5–7 mm. longo; cymis axillaribus, solitariis, junioribus circiter 1.5 cm. longis, dichotomis, paucifloris, pedunculo 5–8 mm. longo, ramis primariis 3–4 mm. longis, 2- vel 3-floris; floribus 5-meris (immaturis), ovario anguste ovoideo, ut videtur 2-loculari; filamentis disci margini insertis; fructibus oblongo-ellipsoideis, 1.5–1.8 cm. longis, perspicue apiculatis, pericarpio viridi, distincte longitudinaliter striato; sepalis persistentibus reniformibus, circiter 1 mm. longis, 1.5–2 mm. latis.

CHINA: Kwangsi, Ping-nan District, Yao Shan, *C. Wang 40779* (A), January 2, 1937, a small shrub in dense forests.

A species in many respects resembling *Microtropis Henryi* Merr. & Freem. of Yunnan, but with somewhat more numerous, less ascending lateral nerves, somewhat shorter petioles, strictly axillary cymes, longer fruits, the green pericarp distinctly striate, 5-merous flowers, and sharply angled ultimate branchlets. It is barely possible that *Tsai 51681*, from Yunnan, a very imperfect specimen, may represent the same species.

25. **Microtropis micrantha** (Hay.) Koidz. Bot. Mag. Tokyo **40**: 335. 1926; Sasaki, Pl. Formos. 274. 1928; Makino & Nemoto, Fl. Jap. ed. 2, 686. 1931; Kanehira, Formosan Trees ed. 2, 396. 1936; Masam. Fl. Formos. 128. 1936.

Cassine micrantha Hay. Ic. Pl. Formos. **3**: 61. 1913.

FORMOSA: Byoritsu, *Kawakami*, not seen (herb. Tokyo), (photo. A).

This species has by far the largest leaves among the Japanese-Formosan species, being chartaceous or membranaceo-chartaceous, the largest ones 10 by 5.5 cm. The number of floral parts is not given in the original description, the type having immature flowers. We judge that the species is closely allied to *Microtropis submembranacea* Merr. & Freem. We are under obligations to Dr. T. Nakai for his courtesy in supplying us with a photograph of Hayata's type.

26. **Microtropis submembranacea** sp. nov.

Microtropis fokienensis sensu Merr. & Chun, Sunyatsenia **2**: 268. 1935, non Dunn.

Frutex glaber, circiter 4 m. altus, ramis teretibus, brunneis vel subpurpureo-brunneis, ramulis junioribus distincte 4-angulatis, circiter 1 mm. diametro, internodiis 1.5–4 cm. longis; foliis submembranaceis vel subchartaceis, in sicco viridibus vel pallide viridibus, nitidis, subtus paullo pallidioribus, plerumque oblongo-ovatis, 3.5–8 cm. longis, 1.5–3 cm. latis, distincte acuminatis, acumine obtuso, basi late acutis vel acutis et plus minusve decurrentibus; nervis primariis utrinque 5–7, gracilibus, leviter elevatis, arcuato-anastomosantibus, reticulis sublaxis; petiolo circiter 5 mm. ongo; cymis axillaribus, pedunculatis, 1–2 cm. ongis, 1–1.5 cm. latis, paucifloris, dichotomis, pedunculo 5–8 mm. longo, ramis primariis subpatulis, ad 4 mm. longis, 3-floris, flore centrali sessili, duobus lateralibus breviter pedicellatis; floribus 5-meris, circiter 3 mm. longis, pallidis, bracteis oblongo-ovatis, acutis, 1 mm. longis, margine minute erosis, bracteolis ovatis, 0.5 mm. longis; sepalis leviter rugosis, late ovatis vel subreniformi-ovatis, rotundatis, circiter 1 mm. longis, haud erosis; petalis membranaceis, ellipticis, rotundatis, circiter 2.5 mm. longis; disco 5-lobato, staminibus circiter 1 mm. longis, inter lobis disci insertis; ovario ovoideo, 2-loculari; fructibus viridibus, laevibus, ellipsoideis vel leviter obovoideis, apiculatis, circiter 1.5 cm. longis, pericarpio obscure striato.

CHINA: Kwangtung, Yu-Yuen District, Tsing Kai Tung, *Y. Lee 2090* (A); Sun-Yi District, *C. Wang 37901, 37895*, November 17, 1934 (A). Hainan, Poting, *F. C. How 73635, 73628* (A), Sept. 4, 1935, in forests, alt. 1000 m.; Five Finger Mountains, and without locality, *C. Wang 35276* (type), *35278, 35538, 35652, 36559* (A, N); Fan Yah, *N. K. Chun & C. L. Tso 44040* (A, N), a shrub 4 m. high in forests, alt. 1000 m.

This species is particularly characterized by its disk being distinctly lobed, the filaments attached to the margins of the disk and alternating with the lobes. The disk lobes are usually about twice as wide as long, broadly rounded, truncate, or obscurely 2-toothed, mostly about 0.25 mm. long and 0.5 mm. wide.

27. **Microtropis Petelotii** sp. nov.

Frutex vel arbor glabra, circiter 15 m. alta, ramis teretibus, lenticellatis, purpureo-brunneis, ramulis plus minusve 4-angulatis, 1.5 mm. diametro; foliis oblongo-ellipticis vel oblongis, chartaceis, 8–13 cm. longis, 2.5–5 cm. latis, pallide olivaceis, opacis, utrinque subaequaliter angustatis, apice acutis vel leviter acuminatis, basi acutis, margine plerumque pallidis, nervis primariis utrinque 7–10, gracilibus, haud perspicuis, arcuato-anastomosantibus laxe reticulatis; petiolo 8–10 mm. longo; cymis axillaribus vel supra-axillaribus, solitariis, pedunculatis, usque ad 3 cm. longis, 2–3 cm. latis, ter-dichotomis, pedunculo 1–1.5 cm. longo; floribus plerumque in triadibus in ramulis ultimis dispositis, flore mediani sessili, lateralibus brevissime pedicellatis; bracteis bracteolisque triangulari-ovatis, subacutis vel obtusis, margine brunneis, brevissime ciliatis; floribus numerosis, 5-meris sepalis concavis, reniformi-orbicularis, rotundatis, 1 mm. longis, margine breviter ciliato excepto glabris; petalis tenuibus, oblongo-ellipticis, 2.5–3 mm. longis, 1–1.2 mm. latis, apice rotundatis; staminibus extra marginem disci insertis, filamentis circiter 1 mm., antheris subreniformibus, vix 0.5 mm. longis; disco tenui, truncato, circiter 2 mm. diametro, 0.8 mm. alto; ovario glabro, ovoideo, 2-loculari, stylis crassis, 0.5 mm. longis; fructibus immaturis subcylindraceis, rectis vel leviter curvatis, acutis vel apiculatis, circiter 12 mm. longis, 3–4 mm. crassis.

INDO-CHINA: Tonkin, Fan Tsi Pan, route to Lo Qui Ho, near Chapa, altitude about 1900 m., *Pételot 4428* (A type, N). CHINA: Yunnan, Mengtze, *Henry 11417* (K), 10491 (abnormal fruit) (A, M), 10491A (abnormal fruit) (A, K); Ping-pien Hsien, *Tsai 61953* (A); Kwangsi, without locality, *Lau 24879* (A).

This species is characterized by its peduncled, rather lax, thrice dichotomous cymes that are about as wide as long, but much shorter than the leaves. The larger and usually rostrate-acuminate fruits of *Henry 10491*, which are 1.5 to 2.5 cm. long, are abnormal, due to the presence of insect larvae. The filaments are attached to the free disk on its back just below the margin.

28. **Microtropis fokienensis** Dunn, Jour. Linn. Soc. Bot. **38**: 357. 1908, **39**: 469. 1911; Dunn & Tutcher, Kew Bull. Add. Ser. **10**: 61. 1912; Rehder, Jour. Arnold Arb. **11**: 165. 1930 (p. p.), **18**: 216. 1937.

Myrsine Chaffonjoni Lév. Fl. Kouy-Tcheou 287. 1914; Rehd. Jour. Arnold Arb. **18**: 216. 1937.

Cassine illicifolia Hay. Ic. Pl. Formos. **3**: 60. 1913.

Cassine Matsudai Hay. Ic. Pl. Formos. **9**: 18. *t. 11*. 1920.

Otherodendron Matsudai Hay. l. c. in syn.

Microtropis Matsudai Koidz. Bot. Mag. Tokyo **40**: 335. 1926; Sasaki, Pl. Formos. 274. 1928; Mak. & Nem. Fl. Jap. ed. 2, 685. 1931; Masam. Fl. Formos. 128. 1936.

Microtropis illicifolia Koidz. Bot. Mag. Tokyo **40**: 334. 1926; Sasaki, Pl. Formos. 274. 1928; Mak. & Nem. Fl. Jap. ed. 2, 685. 1931; Kanehira, Formos. Trees ed. 2, 394. *f. 352*. 1936; Masam. Fl. Formos. 128. 1936.

Microtropis illicifolia Koidz. var. *yunnanensis* Hu, Bull. Fan. Mem. Inst. Biol. **7**: 214. 1936.

CHINA: Anhwei, Wengshan, *Cheng 4197* (Su); Hwan Shan, *Ling 1184* (9610), *Ching 3021* (A, Su); Chekiang, Tien Tai Shan, *Chiao 14480* (A, E, U, UC); Tihtaishan, *Ching 1427A* (N); Fukien, Hinghwa Distr. *Chung 1046* (UC); Yenping, *Dunn 2394*, isotype (A, Su); Kwangsi, Tong Shan, Waitsap Distr., *Tsang 22791* (A); Kwangtung, Swatow, *Dunn 17260* (Su); Kweichow, Kouy-yang, *Bodinier & Chaffanjon 2048*, type of *Myrsine Chaffonjoni* Lév. (photo. & fragm. A); Chengfeng, *Tsiang 4350* (N, Su, UC, photo. A); Kiao-Feng San, Pinfa, *Teng 875* (Su); Szechuan, Nanchuan-hsien, *Fang 5756* (E); Yunnan, *Forrest 17728* (A, E), distributed as *Olea* and as *Sarcococca;* Kambaiti & Tengyueh, *Rock 7536* (A, N, U, UC); Wenshan Hsien, *Tsai 51664* (A), *51738* (A); no locality, *Tsai 55986* (A) (the type collection of *M. illicifolia* var. *yunnanensis* Hu). FORMOSA: Arisan, *Faurie 1538* (M), *Wilson 9746* (A), *10847* (A), *10916* (A); *Kanehira & Sakaki 68* (A); *Kanehira 3066* (N), *3067* (U, N, fragm. A); *Faurie 1538* (M); Mount Buizan, April 1919, *Matsuda* (photo. A), type of *C. Matsudai;* Bunkoko, *Faurie* 1669 (M); Mount Daibuzon, Jan. 1919, *Matsuda 306* in Herb. Univ. Taihoku (fragm. A).

In comparing *M. illicifolia* Koidz., and *M. illicifolia* Koidz. var. *yunnanensis* Hu with *M. fokienensis* Dunn, no constant tangible differences were noted. In the Formosan specimens the flowers seem to be constantly 4-merous, while in Chinese material representing *M. fokienensis* they are indifferently 4- and 5-merous. The only difference we have noted as between Formosan and Chinese material is that on the normally 3-flowered peduncles, the lateral flowers are sessile in the Chinese plants and are very slightly pedicelled in the Formosan specimens. The type of *M. Matsudai* Koidz. was from Formosa, but judging from the scanty material we have seen representing this species, it is scarcely to be distinguished from *M. illicifolia* Koidz. = *M. fokienensis* Dunn.

Series DISCOLORES

Leaves small or medium, acuminate; cyme short, few-flowered; disk entirely wanting, the stamens attached to the basal parts of the petal and alternate with them, the petals keeled inside fruits (unknown in one species) subfurfuraceous lepidulote. India, Burma, Siam, Indo-China Yunnan, ? Penang.

29. **Microtropis discolor** (Wall.) Wall. List no 4337, 1830; Arnott, Ann. Nat. Hist. **3** 151. 1839; Lawson in Hook. f. Fl. Bri Ind. **1**: 614. 1875; Kurz, Jour. As. Soc Bengal **44** (2): 160. 1875, For. Fl. Bri

Burma **1**: 251. 1877; Gamble, Trees Shrubs Darjeeling 18. 1878; Duthie, N. W. Ind. Pl. 37. 1885; King, Jour. As. Soc. Bengal **65** (2): 341. 1896 (Mater. Fl. Malay. Penin. **2**: 627); Strachey, Pl. Kum. 32. 1906; Ridley, Fl. Malay Penin. **1**: 444. 1922; Craib, Fl. Siam Enum. **1**: 281. 1926; Kanj. & Das, Fl. Assam **1**: 267. 1937.

Cassine discolor Wall. in Roxb. Fl. Ind. **2**: 378. 1824.

Ilex dipyrena Wall. List quoad no. 4327B. 1830, *nomen nudum*.

Euonymus garcinifolius Wall. in Roxb. Fl. Ind. **2**: 403. 1824, ed. 2, **1**: 628. 1832; Drury, Ind. Fl. **1**: 231. 1864.

Microtropis garcinifolia Wight, Ic. Pl. Or. **3** (1): 4. *t. 761*. 1843; Kurz, Jour. As. Soc. Bengal **44** (2): 160. 1875.

Microtropis pallens sensu Craib, Fl. Siam. Enum. **1**: 281. 1926, non Pierre.

INDIA: Assam, no definite locality, *Bal 693* (C), *Griffith* s. n. (C, N), *Jenkins* s. n. (E, C, L), *Masters* s. n. (C), *Mann* s. n. (C); Abor Expedition, *Burkill 36277, 36386, 36484* (C); Lushai Hills, *Parry* s. n. (C), *Gage 159* (C); Kohima, *Clarke 41399A* (C), *41399B* (C); Kohima, *Clarke 41399A* (P); Jowai, *King's collector* s. n. (C); Jaintia Hills, *King's collector* s. n. (C), *Clarke 17855* (P), *18016* (E); Baligau, near Naga Hills, *Prain's collector 424, 488* (C); Nukin Hills, *Masters* s. n. (C); *Simons* (E, L, P); Khasia Hills, no collector, Aug. /50 (C), no collector *106* (C); Jarain, *Kanjibal 2723, 2600, 2817* (C); *native collector Calcutta Bot. Gard.* s. n. (C, L, P, photo. A); Mariao, *Clarke 14283* (C), *15363* (C, P); Maododoom, *Clarke 42916* (C, P), *Gammie 463* (C); *Griffith* s. n. (Gr, L); *Hooker & Thomson* s. n. (C, E, Ge, L, N, P); *Kurz 106* (C, narrow leaved form), *296* (C); *McClelland 1846* (C); Nya Bungalow, *Clarke 37315, 37321* (U); Bengal, *Clarke 27508* (P), *9716* (P), *9718* (C, P), *13577* (E, P); *Griffith 1980/1* (C, Ge, L, N, P); Jalpaiguri, *Parker* s. n. (A); Khontimari, *Parkinson 3458* (A, Gr, N); no locality, *Hamilton 619* (E); Jaldaka Valley, Chumbi, *Searight 126* (C); Duphla Hills, *Lister 122* (C); Kossyah & Jynteah Hills, *Gallatly 66* (C); Rumpet, *Clarke 12587B* (C); Sakha hora, *Prain's collector* s. n. (C); Sikkim, without ocality, *Kurz* s. n. (C), no collector (Ge), *Ander-on* (P), *Beddome 1293* (P), *Hooker* (C, Ge, Gr, E, , N), *King* in 1878 (P), *128 1/2, 1022, 2315* (C), *Thomson* (Ge, L, P); Khursiong, *Clarke 35931* Ge); Munsong, *Craib 284* (C); Rishap, *Dongboo* (C); Rungbi, no collector (C); Sureil, *Smith 688, 694* (C); Silhet, no collector (C), *Wallich 4337*, type collection (Ge, Gr, M), *4337B* (A, E, Ge, P, photo. A), Kumaon, *Wallich 4327B* (L), issued as *Ilex dipyrena* Wall. No localities or collectors indicated, ex herb. Calcutta (E), ex Herb. Watt (E), *Falconer 230* (C), *McLellan* (E). BURMA: Amherst, Dawna Range, *Lace* (E); Kachin Hills, Shaik Mokim (C); Karen, *Brandis* (C); Katha District, *Lace* (C, E, photo. A); Linainka, *Toppin 6292* (C); Martaban and Pegu, *Kurz 175* (C); Nam Tesong, *Toppin 6308* (C); Nam Tamai, *Ward 9113, 9177* (A); Phyet, *Toppin 6249* (C); Pegu, *Brandis* (C); Mergui, Sandawut, *Parker 2774* (A); King Tung, South Shan States, *MacGregor 1200* (C, E); Tenasserim, *Beddome 1293* (P), *Helfer 1979* (C), *Meebold 15167, 15363* (C); Molyet, *Gallatly* s. n., 372 (C). SIAM: *Kerr 7689, 9295* (E). INDO-CHINA: Bienhoa, *Pierre 837* A (see *M. pallens* Pierre, p. 294 for the Phu Quoc material placed by Pierre under this number); Lakhon, *Thorel 3186* (Ge, E). PENANG: Tiger Hill Road, ? *Haniff 100* (Su, UC, photo. A). CHINA: Yunnan, Che-li Hsien, *Wang 79691* (A), Dahmeng-lung, *Wang 76357, 77898* (A), Kuenger, *Wang 79417* (A), Nan-hsien-ho, *Wang 79493, 79568* (A); Hwei-chu, *Wang 80271, 80290, 80294* (A); Lu-se, *Tsai 56327;* Szemao, *Henry 12686* (A, N).

On comparing the Mekong and Penang material (distinctly incomplete specimens in both cases), we note no very tangible differences between Wallich's material and the Mekong specimens. The Penang plant, however, has a different aspect, with relatively longer and narrower leaves, slenderer petioles, more delicate inflorescences, and smaller flowers. In the distinctly unsatisfactory Penang material examined, although the petals are slightly keeled inside, somewhat as in typical *M. discolor* Wall., the stamens are not attached to the bases of the petals but are apparently inserted on a vestigial disk. It may later prove to be desirable to separate the Penang form when more material is available, especially as King states that its fruit, which we have not seen, is smaller than that of the Indian plant. He describes it as subglobular, glabrous, and 0.3 in. long; that of the typical form is ellipsoid, 1 to 1.5 cm. long, and the pericarp is roughish and distinctly subfurfuraceous-lepidotulote, the latter a character that we have not seen mentioned in any formal description of the species. It holds for the Khasia, Assam, Bengal, Burma and Yunnan material, as far as fruiting specimens are available from those regions. We feel that in all probability some forms, among the above cited specimens, especially where only incomplete material is now available, may later prove to be worthy of segregation when more complete specimens are at hand; this applies especially to the Penang form and to that of Indo-China (the form erroneously placed by some authors under *M. pallens* Pierre).

We call attention to the fact that *Microtropis discolor* Wall. is the type or standard species of the genus. It differs from most other species now placed in *Microtropis* in the entire absence of the disk, the filaments alternating with the petals, attached to and uniting their bases; in its petals being rather prominently keeled inside; and in its subfurfuraceous-lepidotulote fruits. If the presence or absence of the disk be any criterion in establishing generic limits, then strictly *Microtropis* Wallich should be limited to the few otherwise mostly very diverse species characterized by the absence of the disk (*M. discolor* Wall., *M. pallens* Pierre, *M. Scottii* Parkinson, *M. tenuis* Symington, and *M. valida* Ridley, an incongruous group). Most of the other species here retained in *Microtropis* should then be transferred to one or the other of the generic names discussed above, *Paracelastrus* Miquel, *Otherodendron* Makino, and *Chingithamnus* Handel-Mazzetti; and of these *Paracelastrus* is the oldest. The disk is common to all three categories.

30. **Microtropis pallens** Pierre, Fl. Forest. Cochinch. **4**: *t. 305b.* 1891; Pitard in Lecomte, Fl. Gén. Indo-Chine **1**: 879, *f. 110.* 1912; Craib, Fl. Siam. Enum. **1**: 281. 1926.

Pleurostylia pallens Pierre l. c. in syn.

INDO-CHINA: Phu Quoc Island, *Pierre 827* (M, P, photo. A). SIAM: Tassan Champhon, *Hamid 3848* (M, S).

Thorel, Mekong Expedition (fragm. A) was cited by Craib and Pitard cites *Harmand 963* (fragm. A) from Annam; both of these specimens we believe to represent a form of *M. discolor* Wall. Craib cites several other collections which we have not seen. *Pierre 837* is the type, but this number consists of material from at least three different collections and from three different localities, Phu Quoc,[1] Feb., 1874, Mount Tamiri, Cambodia, May, 1870, and Bienhoa, Sept., 1865, representing two distinctly different species.

The name *pallens* is distinctly more descriptive of the Bienhoa specimen, but as Pierre's description and his illustration of the flowering branch was clearly made from the Phu Quoc collection, it is only logical to accept this as the type. The Bienhoa specimen of *Pierre 827*, of which we have seen only sterile material, looks like a rather small leaved form of *M. discolor* Wall. and we have placed it in that category; it has but about six pairs of lateral nerves, as does Wallich's species. *M. pallens* Pierre, as we have limited the species (the Phu Quoc specimen only) is amply distinct from *M. discolor* Wall. The two sheets that we have examined have 9 or 10 pairs of lateral nerves; Pierre says 11 or 12 pairs as does Pitard. The flowers are very much smaller than are those of *M. discolor* Wall., the petals being but 2 mm. in length and not conspicuously thickened-keeled in the median portion inside as in Wallich's species. Like *M. discolor* Wall. there is no disk, the filaments being slightly attached to the bases of the petals and alternate with them

Series JAPONICAE

Leaves small, coriaceous, obtuse or rounded often pale when dry, the short cymes usuall more or less glaucous; disk somewhat thickened Japan to Formosa.

31. **Microtropis japonica** (Franch. & Sav Hall. f. Meded. Rijks Herb. **1910**: 3 1911, reprint. 33. 1923; Masam. Pre Rep. Veg. Yak. 92. 1929, Mem. Fac. Sc Agr. Taihoku Univ. **11**: 280. 1934 (F & Geobot. Yak. 280).

Elaeodendron japonicum Franch. & Sa Enum. Pl. Jap. **2**: 315. 1879; Maxi Bull. Acad. Sci. St. Pétersb. **27**: 45 1881 (Mél. Biol. **11**: 205); Ito & Matsu Jour. Col. Sci. Univ. Tokyo **12**: 37 1899 (Tent. Fl. Lutch. **1**: 107); Matsu & Hay. op. cit. **22**: 84. 1906 (Enum. Formos. 84).

Cassine japonica O. Kuntze, Rev. Gen. **1**: 114. 1891; Loesener in Engl. & Pran Nat. Pflanzenfam. **3** (5): 215. 18 Matsum. Bot. Mag. Tokyo **12**: 62. 18 Ito & Matsum. Jour. Col. Sci. Un Tokyo **12**: 375. 1899 (Tent. Fl. Lut **1**: 107).

Otherodendron japonicum Makino, B Mag. Tokyo **23**: 62. *f. 1–25.* 1909;

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[1] Phu Quoc is an island off the southwest coast of Cambodia. Bienhoa is in Cochin-China just north of Saigon, on the southeast coast of Indo-China.

Pl. Japon. **1:** *t. 12–14.* 1911; Matsum. Ind. Pl. Jap. **2:** 323. 1912; Makino & Tanaka, Man. Fl. Jap. 330. 1927; Makino & Nemoto, Fl. Jap. ed. 2, 686. 1931; Terasaki Nippon Shokob. Zuhu *f. 36.* 1933; Naito & Kaj. Wild Pl. Kag. Pref. 389. 1934.

Cassine kotoensis Hay. Ic. Pl. Formosa **3:** 61. 1913.

Otherodendron liukiuense Nakai, Bot. Mag. Tokyo **36:** 67. 1922.

Microtropis liukiuensis Koidz. Bot. Mag. Tokyo **40:** 334. 1926.

Microtropis kotoensis Koidz. Bot. Mag. Tokyo **40:** 334. 1926; Sasaki, Pl. Formos. 274. 1928; Makino & Nemoto, Fl. Jap. ed. 2, 686. 1931; Kanehira, Formosan Trees ed. 2, 395. 1936; Masam. Fl. Formos. 128. 1936.

JAPAN: Honshiu, Idzu, ex herb. Sakurai (A, E); *Yokohama Nursery Co.* (E), *Wilson* s. n. (A), Wilson 8194 (A, E); Suruga, no collector (A, P); Sagami, Mount Takatori, *Sawada* (UC); Tokyo, cult., *Kanehira 3125* (A); *Yokohama Nursery Co.*, cult. (E); Kyushu, Mount Kirishima, *Tashiro* (A); Yakusima, *Masamune* (N); no locality, *Franchet 2007* (P); Riukiu Islands, Osima, *Okabo 59* (P), no collector (P), *Yokohama Nursery Co.* (A), *Kanehira 3297* (photo. A), *3422* (N), photo. of type of *Otherodendron liukiuense* Nakai, herb. Tokyo (A); Formosa, Botel Tobago Island, *Sasaki* s. n. (A), photo. of type of *Otherodendron kotoense* Hay., herb. Tokyo (A).

While we admit that there are slight differences between specimens from the Riukiu Islands (*Microtropis liukiuensis* Koidz.) and Honshiu (*M. japonica* Hall. f.), we have failed to note constant and dependable characters by which two species may be distinguished; and yet as late as 1931 Makino, the author of the genus *Otherodendron*, retained *O. japonicum* Mak. (*M. japonica* Hall. f.) as generically distinct from *Microtropis liukiuensis*. *Microtropis kotoensis* might be distinguished on geographic grounds, with thus one northern, one central, and one southern species, but we have not detected any characters that are sufficiently consistent to permit definite separation. Except for its somewhat more slender inflorescences, *M. kotoensis* Hay. is hardly distinguishable from typical specimens of *M. japonica* from Honshiu. Although the specimens from the Riukiu Islands have a superficially different aspect, one notes that the so-called distinguishing characters, the somewhat coarser, stiffer texture of leaves and the assumed different bark, are also found in some of the Honshiu material, and that the transition from one condition to the other is so imperceptible and intangible that we consider it to be impracticable to distinguish the two forms as separate entities.

32. **Microtropis Sakaguchiana** Koidz. Pl. Nov. Amani-Osim. 16. 1928; Makino & Nemoto, Fl. Jap. ed. 2, 686. 1931; Koidz. Act. Phytotax. Geobot. **1:** 173. 1932.

RIUKIU ISLANDS: Okinawajima (Utchina), Kunchar Sade, *Sonohara* (Herb. Kyoto), (photo. A); Kunigami-gun, *R. Kanehira 3275* (6315), Jan. 5–6, 1934 (fragm. A).

The original description was based on two collections, that of Sayuka Sonohara, March 21, 1921, and another by Z. Tashiro, Feb. 11, 1924. The species is characterized by its narrow obtuse leaves. The original description is repeated, with slight changes, in Koidzumi's 1932 paper cited above. We are under obligations to Dr. Koidzumi for his courtesy in sending an excellent photograph of the type specimen, and to Dr. R. Kanehira for a loan of his number 3275 (6315) from Kunigami-gun. The flowers are much smaller than are those of *Microtropis japonica* (Franch. & Sav.) Hallier f.

Series JAVANICAE

Leaves caudate-acuminate, base decurrent; cymes rather few-flowered, about as long as the petioles. Java.

33. **Microtropis javanica** sp. nov.

Microtropis bivalvis sensu Koord. Exkursionsfl. Java **2:** 524. 1912; Koord.-Schum. Syst. Verzeich. Herb. Koord. **1** (1, 158): 3. 1912; Koord. & Val. Atlas Baumart. Java **1:** *t. 138.* 1913, non Wall.

Arbor glabra circiter 15 m. alta, ramulis gracilibus, teretibus, brunneis, ultimis subcompressis, 1 mm. diametro, internodiis 6–8 cm. longis; foliis ovatis vel elliptico-ovatis 8–10 cm. longis, 3–5.5 cm. latis, graciliter caudato-acuminatis, basi decurrentibus, in sicco brunneis, utrinque concoloribus, supra nitidis, nervis primariis utrinque 4–6, arcuato-anastomosantibus, gracilibus, subtus paullo elevatis, reticulis laxis; petiolo 1.5 cm. longo; cymis axillaribus, paucifloris, dichotomis, petiolum subaequantibus, pedunculo circiter 5 mm. longo; floribus (4?)- 5-meris, bracteis 1 mm. longis; sepalis inaequalibus, exterioribus suborbicularibus, 2 mm. diametro, 3 interioribus subreniformibus, circiter 2 mm. longis et 3.5 mm. latis; petalis 1.8 mm. longis; staminibus disci margini insertis, filamentis brevibus; ovario oblongo, sulcato, 2-loculari.

JAVA: Bantam, Gunong Pulusari, *Koorders 9921* β (B, photo. A), very rare, a tree about 15 m. high growing at 1250 m. altitude, June 15, 1892.

This differs radically from *Microtropis bivalvis* Wall., notably in its short peduncled cymes and in the slenderly and sharply caudate-acuminate leaves, which have a very different venation than those of Wallich's species. Dr. Boerlage's dissection notes indicate 4–5 sepals and 4–5 petals, but the illustration cited above, based wholly on this specimen, shows only 5-merous flowers, and the one dissection we made was of a 5-merous flower.

Series FALLACES

Leaves medium; cymes rather long-peduncled, dichotomous; disk rather closely adnate to the base of the petals. Indo-China.

34. **Microtropis fallax** Pitard in Lecomte, Fl. Gén. Indo-Chine **1**: 881. 1912.

INDO-CHINA: Tonkin, Lankok Valley, Mount Bavi, *Balansa 3174*, type collection (L, fragm. & photo. A); Annam, Mount Bana, *J. & M. S. Clemens 3923* (A, N, U, UC), *4250* (A, Ge, N, U, UC), May–July, 1927.

Additional material enables us to supply details of the flower structure as follows. Flowers 5-merous, the sepals unequal, thickened, their margins membranaceous; petals oblong, rounded, about 3 mm. long; anthers oblong-ovoid or ovoid-elliptic, about 1.3 mm. long, the stout short filaments borne on the margin of the 2 mm. long disk which is so closely adnate to the basal parts of the petals that it appears to be a part of them, the stamens alternating with the corolla lobes; ovary and style about 2 mm. long, the ovary narrowly conical, 2-celled.

The type, a fruiting specimen, is *Balansa 3174*, although the collection number is not given in the original and only published description, it there being indicated merely as "Tonkin —— Lankok, au mont Bavi (Balansa)." We refer the two Clemens numbers here, although the leaves average smaller than in the type, and the infrutescences are somewhat shorter and with fewer fruits. The original description is somewhat misleading in that the lateral nerves are described as "nervures 16–20"; the primary ones are but 8 to 10 or at most 12 on each side of the midrib, the total number on both sides of the midrib having been counted by Pitard. Dr. H. Humbert kindly supplied us with a leaf from the holotype in the Paris Herbarium, and there is a duplicate in the Rijks Herbarium, Leiden.

Series ELLIPTICAE

Leaves coriaceous to chartaceous; cymes mostly greatly reduced, short-peduncled or sometimes almost sessile, the often crowded flowers subfasciculate. Malay Peninsula, Sumatra, Borneo.

35. **Microtropis elliptica** King, Jour. As. Soc. Bengal **65** (2): 340. 1897 (Mater. Fl. Malay. Penin. **2**: 626); Ridl. Fl. Malay Penin. **1**: 444. 1922.

Microtropis vinculans Boerl. & Koord. in Koord.-Schum. Syst. Verzeich. Herb. Koord. **2**: 33. 1911.

MALAY PENINSULA: Perak, *King's Collector 4193* (Ge, S); Pahang, *Jaamat 25179* (S); Malaya, without locality, but either from Malacca or Penang, probably the latter, *Maingay 945/2* (Gr, K); Malacca, Mount Ophir, *Ridley 3311* (S). PENANG: *Curtis 345* (S), *968* (S), *1531* (K, S), *Ridley* s. n. (S), *King's Collector 1582* (C). SUMATRA: Pang Kalan-Dule, Central Sumatra, Yzerman Expedition, *Koorders 21297* (B, photo. A), March 26, 1891, holotype of *Microtropis vinculans* Boerl. & Koord.

As King indicated no type, the first specimen cited in the original description, *Maingay 945/2* should probably be selected. From the rather fragmentary type of the Sumatran *Microtropi vinculans* Boerl. & Koord. we see no reason fo attempting to retain this as a distinct species The leaves are an excellent match for those o King's species; the flowers on the type are al detached and immature.

36. **Microtropis borneensis** sp. nov.

Frutex vel arbor parva, ad 7 m. alta, glabr ramis teretibus, brunneis vel pallide brunnei ramulis 1.5–2 mm. diametro, subcompressis v sulcatis, vix angulatis, internodiis 1.5–7 cm longis; foliis coriaceis, rigidis, ellipticis, oblong ellipticis vel subovatis, 6–13 cm. longis, 3–5 c latis, margine plerumque leviter revolutis, brev ter, plerumque subabrupte acute acuminatis, ba acutis vel decurrentibus, sicco supra subopac olivaceis vel pallide olivaceis, subtus plerumq brunneis; nervis primariis utrinque 6–8, arcuat

anastomosantibus, supra haud perspicuis, leviter elevatis vel interdum subobsoletis, subtus magis distinctioribus, elevatis, reticulis laxis; petiolo circiter 5 mm. longo, canaliculato; cymis axillaribus, brevibus, vix 1 cm. longis, breviter pedunculatis (pedunculo 2–5 mm. longo), plerumque 3- vel 6- floris, floribus confertis, subcapitatis, sessilibus vel brevissime (vix 1 mm.) pedicellatis, 5-meris; bracteis bracteolisque ovatis, acuminatis, circiter 2 mm. longis; sepalis suborbicularibus, 2–2.5 mm. diametro, rotundatis, margine tenuioribus, sublaceratis fimbriatisque; petalis maturis non visis; filamentis (in alabastro) brevibus, disci margini insertis; ovario anguste ovoideo, sursum angustato, 2-loculari, stigmatibus brevibus, 2- vel 4-lobatis; fructibus oblongo-obovoideis, in sicco brunneis, 2 cm. longis, 1 cm. diametro, breviter crasse apiculatis, sepalis persistentibus ad 3 mm. longis.

Borneo: British North Borneo, Mount Kinabalu, *Griswold 11* (A), June 12, 1937, *Clemens 11077* (A, M), December, 1915, *29512* (A, B, Ge, L), *27850* (B, UC), *29734* (B, L, N), *31434* (A, B, L, N), *31742* (A, holotype; B, Ge, N, UC), *31801* (A, B, L, N, UC), *32471* (A, B, L, N, UC), *32507* (A, B, N). These numerous Clemens collections were made at various localities on Mount Kinabalu, Lumu, Marai Parai, Penibukan, Tenompok, and the Kina Taki, Colombon, and Panataran Rivers, January to June, 1932, and February to June, 1933, at altitudes from 1500 to 2400 m., but in spite of the abundant material examined, 34 sheets in all, none of the specimens examined have mature flowers.

The species is characterized by its rigid, coriaceous, shortly acuminate leaves which are usually dark reddish brown beneath, short petioles, and by its very shortly peduncled, normally 3- or 6-flowered short cymes which do not exceed 1 cm. in length, the sessile or very shortly pedicelled flowers being subcapitate in arrangement. Its closest alliance seems to be with *M. ophirensis* Ridl. of the Malay Peninsula.

37. **Microtropis ophirensis** Ridl. Jour. Roy. As. Soc. Straits Branch **35**: 10. 1901, Fl. Malay Penin. **1**: 444. 1922.

Malay Peninsula: Malacca, Gunong Mering and Gunong Ledang, Mount Ophir, *Ridley* s. n. (S, photos. A). two collections June 6 and 9, 1892, holotype.

This is closely allied to *M. elliptica* King, but nay be retained as distinct. The Gunong Ledang specimen has very short inflorescences about 5 mm. long, but in the Gunong Mering one they are up to 2 or 2.5 cm. in length. The leaves on the two are the same. In the note following the original description Ridley speaks of a form with longer leaves up to 4 inches long, but does not include it in his description. The largest leaves on the type specimen are 8 by 3.5 cm.

38. **Microtropis rigida** Ridl. Kew Bull. 36. 1931.

Borneo: Sarawak, Mount Santubong, *Native Collector* (Bur. Sci.) *2223* (A, M); Mount Matang, *J. & M. S. Clemens 7794* (N, photo. A), Oct. 28, 1929, on forested ridges, altitude about 550 m.; without locality, *Beccari 1702*, type (K, photo. A).

Characterized by its coriaceous very short-petioled or even subsessile leaves which are narrowed below to the abruptly obtuse or rounded or even slightly cordate base, their margins rather prominently revolute, the latter character not mentioned in the original description.

39. **Microtropis ovata** sp. nov.

Frutex circiter 3 m. altus, glaber, ramis teretibus, rigidis, laevibus, subcastaneis, ramulis acute 4-angulatis, 3 mm. diametro, internodiis 3–9 cm. longis; foliis breviter petiolatis vel subsessilibus, crasse coriaceis, rigidis, in sicco utrinque brunneis vel supra olivaceo-brunneis, subopacis vel obscure nitidis, ovatis, late acutis, basi late truncato-rotundatis vel obscure cordatis, 7–10 cm. longis, 5–7 cm. latis, margine plerumque revolutis; nervis primariis utrinque 7–9, distinctis, subtus elevatis, perspicue arcuato-anastomosantibus, reticulis laxis, leviter elevatis; petiolo crasso, 3–4 mm. diametro, minute rugoso, ad 2.5 mm. longo; cymis axillaribus, brevibus, 0.5–1 cm. longis, in sicco castaneis, breviter crasseque pedunculatis, confertis; floribus 5-meris, in sicco castaneis; sepalis late ovatis, circiter 2 mm. diametro, coriaceis; petalis oblongo-ovatis, rotundatis, 2.3 mm. longis; staminibus brevibus, disci margini insertis; ovario ovoideo, 1-loculari.

Borneo: British North Borneo, Mount Kinabalu, Colombon Basin, Numeruk Ridge, *Clemens 40046* (A, holotype, B, L, N); Marai Parai Spur, *Clemens 32592* (B, N). The collections were made on April 4 and August 18, 1933, described as a small shrub, about 8 feet high, altitude 1200 to 1500 m.

A very strongly characterized species, readily recognizable by its very shortly petioled, ovate, rigid, thickly coriaceous, broadly acute leaves which are more or less castaneous when dry,

broadly rounded-truncate or slightly cordate at the base, and by its short crowded cymes, which, although distinctly but shortly peduncled, simulate glomerules.

Series Bicolores

Leaves fairly ample, dark-colored above and very pale brownish beneath when dry; fruit in a terminal fascicle. Borneo.

40. **Microtropis bicolor** sp. nov.

Frutex vel arbor parva, glabra, ramulis teretibus, obscure striatis, 3 mm. diametro, internodiis circiter 8 cm. longis; foliis subcoriaceis, late lanceolatis vel oblongis, 15–20 cm. longis, 4–6 cm. latis, distincte acuminatis, basi cuneatis, in sicco supra subatro-olivaceis, subopacis, subtus pallide brunneis, nervis primariis utrinque circiter 10, rectis, arcuato-anastomosantibus, quam secundaria magis distinctioribus, reticulis ultimis utrinque paullo elevatis; *inflorescentiis terminalibus*, glomeratis, ut videtur paucifloris (floribus ignotis); sepalis persistentibus 4, subcoriaceis, rugosis, margine pallidis, erosis; fructibus sessilibus, oblongo-ellipsoideis, acutis, 1.5 cm. longis, circiter 1 cm. diametro, pericarpio sicco atro-brunneo, laevi.

Borneo: Sarawak, *Beccari 2617* (K, photo. A).

Readily recognized among the large leaved Malaysian species by its flowers being in terminal apparently sessile glomerules, the sessile fruits being about 1.5 cm. long. The upper and lower surfaces of the rather closely reticulated leaves are strikingly different in color, the upper surface being dark olivaceous, the lower pale brown when dry.

Series Gageanae

Leaves medium, chartaceous, very broadly and obtusely blunt-acuminate or merely obtuse, prominently nerved, the nerves curved-anastomosing very close to the margin. Burma.

41. **Microtropis Gagei** sp. nov.

Frutex vel arbor parva, glabra, ramis gracilibus, teretibus, rubro-brunneis, ramulis pallidioribus, obscure sulcatis, circiter 1.5 mm. diametro, internodiis 4–5 cm. longis; foliis chartaceis, plerumque oblongo-ovatis, 9–12 cm. longis, 4–6 cm. latis, utrinque subnitidis, supra olivaceis, subtus pallidis, subglaucis, apice brevissime late obtuseque acuminatis, basi late acutis vel subrotundatis, nervis primariis utrinque 8–10, juxta marginem curvato-anastomosantibus, subtus elevatis, perspicuis, secundariis reticulisque gracilibus, paullo elevatis, supra minus distinctis, leviter elevatis; petiolo canaliculato, 7–9 mm. longo; inflorescentiis axillaribus, breviter pedunculatis, ut videtur paucifloris, sub fructu pedunculo crasso vix 2 mm. longo; fructibus ut videtur solitariis, anguste oblongo-obovoideis, obtusis, 1.6–1.8 cm. longis, pericarpio sicco subcastaneo, tenuissime longitudinaliter striato; sepalis persistentibus ut videtur 5; floribus ignotis.

Burma: Tavoy, ridge between Kyong Pyu Chaung and the Talaingya head stream, *Col. A. T. Gage 37* (C, holotype), February 3, 1919, altitude about 450 m.

Although flowers are unknown, this form is so markedly distinct from the other material we have studied that we unhesitatingly describe it as new. It is well characterized by its very short inflorescences (these in fruit bearing a solitary, very shortly peduncled capsule), and its chartaceous, slightly shining, shortly, broadly, and bluntly acuminate leaves, olivaceous above and subglaucous beneath, the primary nerves elevated and prominent on the lower surface, curved-anastomosing close to the margin.

Series Pachyphyllae

Leaves coriaceous, verruculose when dry, th
short lateral cymes distinctly pedunculate. Siam
Burma.

42. **Microtropis pachyphylla** sp. nov.

Frutex glaber, ad 3 m. altus, ramis teretibu
ramulis ultimis circiter 2 mm. diametro; foliis i
sicco pallidis, rigidis, rugulosis, utrinque concolo
ibus vel subtus paullo pallidioribus, oblongis v
oblongo-ellipticis, nitidis vel subopacis, 8–14 c
longis, 3–5.5 cm. latis, obtusis vel late acutis v
obscure latissime obtuse acuminatis, basi acuti
margine revolutis; nervis primariis utrinque 4–
haud perspicuis, arcuato-anastomosantibus, i
terdum obsoletis vel subobsoletis, secundar
obsoletis; petiolo crasso, canaliculato, 1–1.5 c
longo; cymis lateralibus, in ramis ramulisque i
fra foliis, 3.5–6 cm. longis, dichotomis, rigidis, 3
cm. latis, pedunculis 1.5–3 cm. longis, ra
primariis plerumque 1–1.5 cm. longis, divaricat
dichotomis, secundariis 4–6 mm. longis, florib
in ramulis ultimis plerumque binis, sessilibus
brevissime pedicellatis; floribus albidis, 5-me
circiter 4 mm. longis; sepalis inaequalibus, bi
exterioribus suborbicularibus, circiter 1 m
diametro, interioribus subreniformibus, 1.5 m

longis, 2–2.5 mm. latis; petalis oblongo-obovatis, rotundatis, subconcavis vel subcuculatis, 3.5–4 mm. longis, 2.5 mm. latis; antheris ovoideis, 1.2 mm. longis, filamentis brevibus, crassis, disci margini insertis; ovario anguste ovoideo, 2-loculari.

BURMA: Yatheytaung, Theton District, *6553, Mg-Po-Chin, Forest Ranger*, type, March 24, 1928 (C, photo. A), a small tree in rocky places, alt. 730 m., flowers white; Amherst District, Dawna Range, *Burkill 30313* (C), a small bush with white flowers, alt. about 900 m., March 3, 1908, without locality *Brandis*, ex herb. S. Kurz (C, photo. A).

This form, all specimens originally identified as representing *Microtropis longifolia* Wall., is characterized by its coriaceous, obscurely nerved, pale, verruculose leaves, and differs from *Wallich 4339*, the type of *Microtropis longifolia* Wall. ex Kurz in its very much longer, many flowered, much longer peduncled cymes, those of *M. longifolia* Wall. ex Kurz (in fruit) not exceeding the petioles in length. Although in his original description of Wallich's species, Jour. As. Soc. Bengal **42** (2): 65. 1873, Kurz cites only "Wall. 4339 (pro parte)" he mentions the short cymes with peduncles 4 to 6 lines long, and describes the fruits, we feel confident that the form above described with rather lax cymes much exceeding the petioles in length and with peduncles 1.5 to 3.5 cm. long should not be placed in the same category as *Wallich 4339*, a fruiting specimen, its short peduncled fruiting cymes scarcely equalling or only slightly exceeding the petioles.

43. **Microtropis longifolia** Wall. List no. 4339, 1830, *nomen nudum*, Kurz, Jour. As. Soc. Bengal **42** (2): 65. 1873, *descr.*, For. Fl. Brit. Burma **1**: 250. 1877.

BURMA: Tavoy, *Wallich 4339* (col. Gomez) (C holotype, photo. and drawing A).

We are constrained to limit this species, for the present, to the type collection, *Wallich 4339*, with its holotype in the Calcutta Herbarium. Kurz's Latin description of 1873, based on "Wall. 4339 (pro parte)" and his English one of 1877, appertain to the form here considered and the Wallich specimen in the Calcutta herbarium was the source of his specific name. Other material named at Calcutta as representing *Microtropis longifolia* Wall. we place under *M. pachyphylla* Merr. & Freem., supra. Wallich's species is characterized by its elliptic to oblong-elliptic, coriaceous, verruculose, fairly ample, few nerved leaves and its short infructescences which scarcely equal or but slightly exceed the petioles in length. There has been some confusion regarding the species because the Kew sheet, of which we have an excellent photograph, has mounted with it a specimen of *Salacia macrophylla* Wall. (supposedly = *S. flavescens* Kurz), which, however, has its own label "(303) 1584, tree. Tavoy, 2nd October, 1827." This accounts for the Index Kewensis entry "*longifolia*, Wall. Cat. n. 4339 = latifolia, Salacia flavescens." The mixture was not in the collection but was due to an error in mounting two independent collections on the same sheet.

We have seen no specimen of *Wallich 4339*, our interpretation being based on Kurz's short description and a drawing of the sheet of Wallich's specimen in the Calcutta Herbarium. Mr. Airy-Shaw, who examined the material at Kew, states that he has no doubt as to its representing *Salacia flavescens* Kurz. It may be that the actual specimen in the Calcutta Herbarium represents the *Salacia;* it is a leafy branch with a single detached fruit. In such case *Microtropis longifolia* Wall. would be eliminated from the genus.

44. **Microtropis macrophylla** sp. nov.

Frutex vel arbor parva, glabra, ramulis teretibus, brunneis, 3–4 mm. diametro, internodiis circiter 8 cm. longis; foliis oblongo-ellipticis, in sicco brunneo-olivaceis, utrinque subconcoloribus vel subtus paullo pallidioribus, verruculosis, obscure nitidis, plus minusve acuminatis, basi acutis, 20–23 cm. longis, 7–8 cm. latis, nervis primariis utrinque 6–7, haud perspicuis, subadscendentibus, subtus obscure arcuato-anastomosantibus, secundariis obsoletis vel subobsoletis; petiolo 1.5–1.8 cm. longo, 3 mm. crasso; cymis solitariis vel fasciculatis ad nodos efoliatis, circiter 3 cm. longis, dichotomis, pedunculo 1–1.5 cm. longo, ramis primariis patulis, vix 1 cm. longis, dichotomis; floribus 5-meris, circiter 4 mm. longis; sepalis subreniformibus, subaequalibus, latissime rotundatis, minute denticulato-erosis, 1 mm. longis, 1.5 mm. latis; petalis oblongis, rotundatis, 3 mm. longis, 1.5 mm. latis; filamentis gracilibus, circiter 1.2 mm. longis, disci margini insertis, antheris brevibus, 0.4 mm. longis; ovario conico, 1-loculari.

BURMA: Kachin Hills, *Captain S. M. Toppin*, s. n., type (K, photo. A), without notes.

Although the specimen is somewhat inadequate, we have not been able to match it among the

rather abundant material at our disposal. The species seems clearly to be allied to *Microtropis longifolia* Wall., having even larger leaves than that species, and with more numerous lateral nerves. It differs further in its much larger, longer peduncled cymes.

Series FILIFORMES

Leaves medium to ample, mostly chartaceous; cymes mostly open, twice to several times dichotomous, mostly many flowered, on slender, filiform, often greatly elongated peduncles. Burma, Siam, Malay Peninsula, Penang, Sumatra.

45. **Microtropis filiformis** (Wall.) King, Jour. As. Soc. Bengal **65** (2): 342. 1896 (Mater. Fl. Malay Penin. **2**: 628); Ridl. Fl. Malay. Penin. **1**: 444. 1922.

Euonymus filiformis Wall. List no. 4295. 1830, *nomen nudum*.

MALAY PENINSULA: Perak, *Wray 435* (S, K), *King's collector 2025* (K); Kedah, *Ridley* s. n. (S); Langat, *Ridley 312* (S); Selangor, Sungei Buloh Reserve, *Jaamat 13844* (S), *Symington 22298* (S); Dindings, *Ridley* s. n. (S); Kelantan, *Symington 37643* (S). PENANG: *Wallich 4295* (Ge, K, photo. A), *Curtis* s. n. (S), *Forest Guard 12718* (S). SUMATRA: Asahan, *Rahmat 7613* (A), *7886* (A); Hoeta Padang, *Krukoff 4427* (A, B, Ge, L, M, N); Koaeloe, *Bartlett 7653* (N). Without locality or collector (probably from Penang or the Malay Peninsula) sheet 899, 175–304 (L) "a small plant, name unknown, from the hills, gathered in August, 1824."

In the typical form the flowers are small, up to 3 mm. long, while the leaves usually have from 10 to 12 pairs of lateral nerves. The Sumatra specimens have somewhat shorter and thicker fruits than those of the Malay Peninsula, but the specimens otherwise so closely match those of the Peninsula and Penang that we are convinced that a single species is represented. We have seen no typical *Microtropis filiformis* King material from outside of the Malay Peninsula, Penang, and Sumatra. This species was included by Lawson in Hook. f. Fl. Brit. Ind. **1**: 614. 1875, and by Kurz, For. Fl. Brit. Burma **1**: 251. 1877, in *Microtropis bivalvis* Wall., probably through the erroneous reduction of *Euonymus* ? *laeta* Wall. to the synonymy; see *Euonymus bivalvis* Wall. var. *laeta* (Wall.) p. 301. We are confident that Sir George King was correct in maintaining it as distinct.

A Burma form, characterized by its distinctly larger flowers, which may ultimately best be considered as a distinct species, is:

45a. **Microtropis filiformis** (Wall.) King, var. **grandiflora** var. nov.

Microtropis filiformis sensu Fischer, Kew Bull. 27. 1931, vix King.

A typo differt floribus majoribus 4.5–5 mm. longis. Foliis chartaceis, 10–19 cm. longis, 5–8.5 cm. latis, nervis primariis utrinque circiter 10; pedunculo 3.5–4 cm. longo.

BURMA: Amherst District, Kyain, *F. G. Dickason 6889* (A, type), February, 1938, a shrub about 3 m. high, flowers yellow, on rocky hills; Pegu, Salu Reserve, *Lace 6069* (C, E), a small tree, alt. 75 m., flowers white, fragrant; Mergui, Victoria Point, *Parker 3154* (A), January 29, 1930, a shrub, flowers yellowish-green, and same locality, collector's name illegible, *6292* (C), Dec. 1, 1928, a small tree, alt. about 150 m., flowers whitish.

Superficially the flowers of this variety strongly resemble those of *Microtropis discolor* Wall., but the disk is present, the petals are not keeled inside, and the slenderly, rather long peduncled, many-flowered cymes are very different. Whether considered as a variety, or perhaps eventually as a distinct species, its true alliance is clearly with *M. filiformis* (Wall.) King and not at all with *M. discolor* Wall.

The Siam material referred to *Microtropis filiformis* King by Craib, Fl. Siam. Enum. **1**: 281. 1926, which we have not seen, may represent the above variety or may possibly be referable to *Microtropis bivalvis* (Jack) Wall. var. *laeta* (Wall.) Merr. & Freem.

46. **Microtropis peduncularis** Ridl. Kew Bull. 262. 1924, Fl. Mal. Pen. **5**: 298. 1925, Craib, Fl. Siam Enum. **1**: 282. 1926.

SIAM: Kasum, Khaw Pak Hill, *Haniff & Nur 3842* (M, S, photo. A). MALAY PENINSULA: Kedah, Alor Station, *Ridley 15104* (S); Selangor, Sungei Buluh, *Ridley 13358* (S); Perak, Maxwell's Hill, *Ridley* s. n. (S); Ulo Bubong, *King's Collector 10370* (K, photo. A, type); Langkawi, Gunong Raya, *Haniff*, Feb. 1911 (S).

This species is manifestly very closely allied to *M. filiformis* King, differing in its shorter inflorescences which are usually terminal rather than lateral. In the original description Ridley cites "Perak, Ulu Bubong—Kunstler," but the Ulu Bubong sheet that he wrote up at Kew is *King's Collector 10370*.

47. **Microtropis bivalvis** (Jack) Wall. List no. 4340. 1830; Ettingsh. Denkschr. Akad. Wiss. Wien Math.-Nat. Classe **13**: 64. *f. 13, t. 4. f. 11.* 1857, Blatt-Skel. Dikot. 154. *t. 63. f. 18.* 1861; Lawson in Hook. f. Fl. Brit. Ind. **1**: 614. 1875, pro parte; King, Jour. As. Soc. Bengal **65**: (2): 341. 1896 (Mater. Fl. Malay. Penin. **2**: 627); Ridl. Fl. Malay Penin. **1**: 444. 1922.

Celastrus ? bivalvis Jack, Mal. Misc. **1** (5): 19. 1820; Roxb. Fl. Ind. **2**: 399. 1824; Hook. Bot. Miscel. **2**: 71. 1831; Misc. Pap. Indo-Ch. Ind. Arch. II. **2**: 233. 1837 (reprints of orig. descr.).

Paracelastrus bivalvis Miq. Fl. Ind. Bat. **1** (2): 591. 1859; F. N. Will. Bull. Herb. Boiss. II. **5**: 224. 1905.

? *Euonymus capillaceus* Wall. List. no. 7270. 1832, *nomen nudum* (fide Lawson).

PENANG: *Wallich 4340* (photo. A, E, Ge, Gr, L, N, P), *Maingay 392-2* (Gr, L), *Haniff 246* (N, Su).

We have seen no material from outside of Penang that we feel can safely be referred to this species. King surmised that the plant issued by Wallich as *Microtropis bivalvis* Wall. (for which Wallich cites the synonym *Celastrus ? bivalvis* Jack), was not the plant described by Jack because the latter indicated his species as apetalous, which later led Miquel to propose the new generic name *Paracelastrus* for this particular species. However, it should be noted that *Wallich 4340* is made up of material collected in Penang by Porter and by Jack, and Jack himself speaks of sending specimens of his *Celastrus bivalvis* to Wallich. King surmised that the Penang plant named by Wallich as *Euonymus capillaceus* Wall. might have been the "lost" *Celastrus bivalvis* of Jack, but we see no warrant for this assumption. It is reasonably safe to assume that this Wallich number 4340 does represent the type collection of *Celastrus ? bivalvis* Jack (see p. 272), and that Jack described his species from specimens with fallen petals. Lawson gave the distribution of the species as from Tenasserim to Penang, Malacca, Sumatra, and Java, which is manifestly wrong. King confined it to Penang and Malacca, the latter locality entered on the basis of a Maingay specimen; but Maingay's specimen undoubtedly came from Penang rather than from Malacca, and Ridley was doubtlessly correct in limiting the species to Penang. We are not at all certain that *Euonymus capillaceus* Wall. from Penang, is correctly placed as a synonym of this species, although this is Lawson's disposition of it. No description was ever published and we have not seen a specimen. We judge, from King's statement, Jour. As. Soc. Bengal **65** (2): 342. 1896 (Mater. Fl. Malay. Penin. **2**: 628) in his discussion of *Microtropis bivalvis* Wall., that he thought that some other species was represented, but the specimen that he had for examination lacked both flowers and fruits.

47a. **Microtropis bivalvis** (Jack) Wall. var. **laeta** (Wall.) comb. nov.

Euonymus ? laeta Wall. List no. 4294. 1830, *nomen nudum*.

Microtropis bivalvis sensu Kurz, For. Fl. Brit. Burma **1**: 251. 1877, non Wall.

BURMA: Tenasserim, *Helfer 1930* (Gr, K, L, P, photo. A), *Bot. Surv. 334* (E); Tavoy, *Wallich 4294* (photo. of Kew sheet A, type collection), *For. Dept. 1713* (A), *385* (C); Mergui, *Griffith 849* (Gr, K).

This very closely resembles *Microtropis bivalvis* (Jack) Wall. in vegetative characters and in its slender peduncles, differing mainly in its many flowered cymes, those of typical *M. bivalvis* (Jack) Wall. apparently being but 5-flowered. In other respects it resembles *Microtropis filiformis* (Wall.) King, and was included in that species by Lawson and by King, thus explaining the Burma range of the latter species as indicated by them. It has the fewer-nerved and smaller leaves resembling those of *M. bivalvis* (Jack) Wall., while its peduncles, in length, approximate those of the latter species, those of *M. filiformis* (Wall.) King being much longer.

Series SCOTTIANAE

Leaves medium. Cymes long and slenderly peduncled, thrice dichotomous, nearly as long as the leaves, one large nearly sessile flower in each fork, the ultimate branches with one central sessile or subsessile flower and two lateral slenderly pedicelled ones; flowers large, the petals reflexed. Burma.

48. **Microtropis Scottii** Parkins, Repert. Sp. Nov. **29**: 104. 1931.

BURMA: Tenasserim, Myinmolekat, *Parker 3127* (K, photo. A), alt. 1950 m., type collection.

Striking characters of this species are its very slender, lax, thrice dichotomous inflorescences which approximate the leaves in length, a sessile or shortly and stoutly pedicelled solitary flower in each fork, the ultimate branching a triad with

one subsessile and two slenderly pedicelled flowers. The relatively large reflexed petals are unusual in the genus. Parker describes this as having no disk, but as having the filaments shortly united below. The ovary is 1-celled. This species has the largest flowers of any known representative of the genus.

Series CONFERTIFLORAE

Leaves rather small, the peduncles slender, elongated, the flowers subcapitately crowded; younger parts and inflorescences often with few, widely scattered, stiff, short hairs. China.

49. **Microtropis gracilipes** Merr. & Metc. Lingnan Sci. Jour. **16**: 88. *f. 6.* 1937.

Microtropis gracilipes var. *parvifolia* Merr. & Metc. l. c.

CHINA: Kwangtung, Yam Na Shan, Mei (Kaying) District, *Tsang 21425* (A, N), *21488* (A, N); Tai Mo Shan, Tapu District, *Tsang 21195*, type (A, N).

The description of the species was based on *Tsang 21195* and *21425*, and, superficially, this larger-leaved form does seem to be quite distinct from the smaller leaved one, characterized as *M. gracilipes* var. *parvifolia*. However, the leaf-size varies enough on individual specimens (see *Tsang 21425*) to cause us to believe that the differences in leaf-size scarcely warrant recognition of the variety.

As in *M. confertiflora* Merr. & Freem. here also (see *Tsang 21195*) we find a sparingly pubescent condition on the youngest branchlets, inflorescences, and petioles. The other specimens are strictly glabrous, yet there is no doubt that they represent the same species as the type. This species is distinguished from its close ally, *M. confertiflora*, in its more slender habit, smaller flowers, and proportionately longer peduncles, as well as by its smaller leaves.

50. **Microtropis confertiflora** sp. nov.

Frutex 4–7 m. altus, glaber, vel ramulis obscurissime breviter consperse rigide pubescentibus, ramis teretibus, plerumque, purpureo-brunneis, ramulis plus minusve 4-angulatis vel sulcatis, 1–1.5 mm. diametro, internodiis 1.5–7 cm. longis; foliis oblongis vel oblongo-lanceolatis, chartaceis vel subcoriaceis, in sicco subnitidis, plerumque viridibus, interdum subolivaceis vel subbrunneis, subtus plerumque paullo pallidioribus, 6–13 cm. longis, 1.5–4.5 cm. latis, utrinque subaequaliter angustatis, perspicue acuminatis, basi cuneatis, raro late acutis; nervis primariis utrinque 7–10, gracilibus, utrinque cum secundariis reticulisque leviter elevatis, haud prominentibus; petiolo 5–15 mm. longo; cymis axillaribus extra-axillaribusque, distincte pedunculatis, solitariis, sub anthesi 1–3 cm. longis, plerumque dichotomis, ramis primariis brevibus, 1–3 mm. longis, floribus subcapitatim confertis, capitulis circiter 1 cm. diametro, pedunculo 1–2 cm. longo; floribus omnibus sessilibus, 5-meris, circiter 5 mm. longis, bracteis 1 mm. longis, ovatis, acutis; sepalis inaequalibus, orbiculari-reniformibus, margine breviter fimbriatis, binis exterioribus 2 mm. longis, 2.5 mm. latis, interioribus 2.5 mm. longis, 3.5 mm. latis, omnibus latissime rotundatis; petalis circiter 4.5 mm. longis, distincte stipitatis, ellipticis vel obovato-ellipticis, rotundatis; staminibus 2 mm. longis, filamentis margini disci insertis; ovario ovoideo, sursum angustato, subrostrato, 2-loculari; fructibus oblongo-ovoideis, circiter 1 cm. longis, rostrato-acuminatis, pericarpio longitudinaliter striato, junioribus interdum subfalcatis.

CHINA: Kwangtung, Lok Chong District, *N. K. Chun 42518* (A), type, Jan. 13, 1931, a shrub near streams, flowers white; Tai Tung, *S. P. Ko 51885* (A), *C. L. Tso 21122* (A, N), 7 m. high, in forests, *N. K. Chun 42964* (A), near streams, *S. P. Ko 51153* (A), in forests; Tsing Yuen District, *Y. F. Chun 30685* (A), in ravines; Ying Tak District, Wan Tong Shan, *H. Y. Liang 61321* (A, Su), *61437* (A), a small tree in woods; Yu-Yuen District, Tai Ling, *S. P. Ko 53523* (A), a shrub in forests, flowers white, *S. K. Lau 25305* (A), in forested ravines: Kwangsi, Ping Nan District, *C. Wang 40355* (A), small shrub in dense forests; Tseung District, Yao-shan, *Kwangsi Museum 764* (Su), 7–8 feet high, near streams, *C. Wang 39593, 40124* (A), shrub in dense forests Shap Man Taai Shan, *W. T. Tsang 22639* (A) without locality, *C. Wang 39593, 40124* (A), *T. S Tsoong 83555* (A); Kweichow, Sanhoa, *Y. Tsian 6268* (N, Su), in dense forests, alt. 700 m.

This is a very strongly marked species, distinguished among other characters by its slenderly peduncled, subcapitate cymes, the sessile rathe large flowers being subcapitately crowded, ye the cymes are essentially dichotomous, as ther are usually two very short branches. The rathe obscure, stiff, short, scattered hairs on some of th younger branchlets and occasionally on th petioles and peduncles suggests *Microtrop gracilipes* Merr. & Metcalf, which it resembles

certain other characters, yet the two are clearly distinct. Still another unusual character is the distinctly clawed petals. Many specimens were received from Professor Chun under an unpublished binomial proposed by him. Normally this would have been accepted, but was deliberately abandoned in order to avoid possible confusion, because Ridley had already published *Microtropis peduncularis* for a Malay Peninsula species, and Chun's proposed name differed only in the terminal syllable.

Series CHARTACEAE

Leaves mostly large, the inflorescences of dichotomous cymes (except *M. fasciculata*); fruits as far as known, rostrate. Malay Peninsula, Sumatra, Philippines.

51. **Microtropis longirostris** sp. nov.

Arbor parva, glabra, ramis teretibus, laevibus, brunneis, ramulis ultimis teretibus vel novellis subcompressis, 2–2.5 mm. diametro, internodiis circiter 6 cm. longis; foliis ellipticis, abrupte acuteque acuminatis, acumine 1.5 cm. longo, rectis vel subfalcatis, 17–22 cm. longis, 8–10 cm. latis, basi late acutis vel leviter decurrentibus, in sicco supra leviter nitidis, olivaceis, subtus opacis, brunneis; nervis primariis utrinque 7–10, supra obscuris, subtus distinctis; petiolo 0.5–1.5 cm. longo, rugoso, 2 mm. crasso; cymis extra-axillaribus in ramulis ultimis vel lateralibus in ramis vetustioribus, plerumque solitariis, paucifloris, 2–2.5 cm. longis, pedunculo 0.5–1.5 cm. longo; floribus 5-meris, bracteis circiter 1 mm. longis; sepalis suborbiculari-reniformibus, 1 mm. longis; petalis oblongis, rotundato-obtusis, 3 mm. longis; staminibus margini disci insertis; ovario 2.5 mm. longo, 4-sulcato, 2-loculari; fructibus (cum rostro) 3 cm. longis 8–10 mm. crassis ellipticis, pericarpio minute ruguloso, obscure striato, brunneo, rostro gracili, 10–12 mm. longo.

MALAY PENINSULA: Pahang, Camp 4, Cameron's Highlands, *Henderson 11211*, type (S, photo. A); Kemanan, Ulo Bendong, Kajang, *Corner 30103* (S, photo. A), a small tree, alt. 1200–1400 m.

Among the very large leaved forms this species is immediately distinguished by its slenderly long-beaked capsule. Its general alliance seems to be with *M. elliptica* King but it is distinguished not only by its very different fruits and inflorescences, but also by its very much larger leaves.

52. **Microtropis chartacea** sp. nov.

Frutex glaber, circiter 1 m. altus, ramis ramulisque pallide brunneis, teretibus, vel novellis obscure subcompressis, ultimis 2 mm. diametro, internodiis 10 cm. longis; foliis tenuiter chartaceis, ellipticis vel oblongo-ellipticis, obtuse subabrupte acuminatis, basi acutis vel decurrentibus, 13–20 cm. longis, 5–9 cm. latis, in sicco supra olivaceis, subtus pallide brunneis; nervis primariis utrinque 8–10, gracilibus, utrinque distinctis, arcuato-anastomosantibus; petiolo 1.5–2 cm. longo; cymis axillaribus, solitariis, paucifloris, circiter 1 cm. longis, pedunculo 2–5 mm. longo; floribus 5-meris, sepalis persistentibus, rotundatis, chartaceis, brunneis, margine erosis; fructibus oblongo-ellipsoideis, 2–2.5 cm. longis, circiter 1 cm. diametro, rostrato-acuminatis, in sicco atro-brunneis, laevibus.

PHILIPPINES: Luzon, Camarines Sur Province, Sarapan and Kamagong, on dry forested slopes, altitude about 400 m., *Edaño 75880, 76174* (N, M, photo. A), on forested slopes, altitude about 500 m.

The alliance of this species is apparently with *M. philippinensis* Merr. Flowers are not available.

53. **Microtropis fasciculata** Quis. & Merr. Philip. Jour. Sci. **37**: 162. 1928.

PHILIPPINES: Panay, *Edaño 46147* (A, N, U, UC, photo. A).

In vegetative and fruit characters very similar to *Microtropis rostrata* Merr. The fruits are, however, strictly fasciculate, the fascicles borne on the trunk and larger branches.

54. **Microtropis pauciflora** Boerlage in herb., sp. nov.

Frutex vel arbor parva, glabra, inter species cum foliis majoribus, ramis teretibus brunneis vel rubro-brunneis, ultimis circiter 2 mm. diametro, internodiis 5–10 cm. longis; foliis oblongo-ellipticis, chartaceis, pallide olivaceis, utrinque nitidis, subtus paullo pallidioribus, 14–28 cm. longis, 5–10 cm. latis, apice perspicue subabrupte acuminatis, basi late acutis, nervis primariis utrinque 12–14, quam secundaria vix magis distinctioribus; petiolo 1.5–2 cm. longo; cymis brevibus, paucifloris, simplicibus, axillaribus, solitariis, circiter 0.5 cm. longis, pedunculis sub anthesi vix 5 mm. longis, sub fructu usque ad 1 cm. longis; floribus 5-meris; sepalis suborbicularibus, circiter 2.5 cm. diametro; petalis late ovatis, rotundatis; ovario cylindrico, 2-loculari; fructibus in sicco atrobrunneis, anguste ovoideis, breviter apiculatis, circiter 1.5 cm. longis.

SUMATRA: without locality, *Korthals* s. n. (A, B, L, type), the several sheets in the Rijks Herbarium all entered under no. 201580.

The material consists largely of branchlets and leaves, most of the specimens being sterile. In vegetative characters they are similar to *Microtropis sumatrana* Merr., but the short, few-flowered, simple cyme seems to be characteristic.

55. **Microtropis sumatrana** Merr. Pap. Michigan Acad. **19**: 164. *t. 26* (1933) 1934.

SUMATRA: East Coast, Marbau, Bilah, near Bilah Pertama, *Rahmat 214*, type, *375* (not *275*) (A, N); West Coast, Simaloer Island, *Achmad 34* (B), *97* (B), *185* (B, L, photo. A), *704* (B, L), *1222* (B, L, photo. A), *1528* (B, L, M); Batoe Island, *Raap 695* (B); no collector or locality indicated, *Hort. Bogor. 149* (L).

The description and illustration indicate 8 or 9 primary nerves on each side of the midrib; but some of the Rahmat material has as many as 12 pairs of nerves. The Simaloer specimens tend to have smaller leaves; in other respects the plants from the east and west coasts are sufficiently alike to warrant their being considered to represent a single species. The "stipules" indicated as 2–2.5 cm. long in the original description are merely incipient leaves, and mm. should be substituted for cm.

56. **Microtropis philippinensis** Merr. Philip. Jour. Sci. Bot. **13**: 306. 1918; Enum. Philip. Fl. Pl. **2**: 482. 1923.

PHILIPPINES: Catanduanes, Mount Mariguidon, *Ramos 30580* (A, M, U) type.

This species is known only from the type collection, which consists of fruiting specimens. *Microtropis rubra* Elmer, erroneously placed by the senior author in 1923 as a synonym, has paniculate-cymose inflorescences, not the dichotomous ones of *M. philippinensis* Merr. and is amply distinct; see p. 305.

Series CYMOSO-PANICULATAE

Leaves various, small to large, chartaceous to stiffly coriaceous; inflorescences paniculate-cymose, not strictly dichotomous; i. e., the rachis extended above the first pair of lateral branches, the few branches racemosely arranged; disk present (except in *M. tenuis* and *M. valida*). Malay Peninsula, Borneo, Philippines.

57. **Microtropis tenuis** Symington, Jour. Malay. Br. Roy. As. Soc. **14**: 350. *t. 19.* (1936) 1937.

MALAY PENINSULA: Pahang, Gunong Tapis, Kuantan, *Symington 28818* (not *28878*) (S, photo. A), June 13, 1934, altitude about 600 m., type.

By its very obscure or obsolete disk this might be placed in the group with *Microtropis discolor* Wall. with which, however, it does not otherwise closely conform. It has the characteristic, although much reduced cymose-paniculate inflorescences of the group in which it has been placed rather than strictly dichotomous ones. It is, however, not closely allied to any other species placed in this assemblage. By error in the original description the type number was cited as *28878 Symington;* it is *28818.*

58. **Microtropis valida** Ridl. Jour. Roy. As. Soc. Straits Branch **75**: 19. 1917, Fl. Malay Penin. **1**: 445. 1922.

MALAY PENINSULA: Perak, Hermitage, alt. about 900 m., *Curtis 1331* (K, S, photo. A).

A species strongly characterized by its elongated, stout, many-flowered paniculate cymes among those species with coriaceous leaves and 4-merous flowers.

Ridley states "Petals connate below, lobes 4 short, broad, rounded. Stamens 4 inserted or the tube, filaments broad." We note no disk but the petals are free or nearly so, their base apparently slightly united by the alternate filaments as in the otherwise unrelated *M. discolo* Wall.

59. **Microtropis kinabaluensis** sp. nov.

Frutex glaber, ramis teretibus, rigidis, ramul 2–3 mm. diametro, teretibus vel subcompressi internodiis 2.5–6 cm. longis; foliis plerumq ellipticis vel late oblongo-ellipticis, subcoriacei in sicco pallide subolivaceis, subtus paul pallidioribus, 10–20 cm. longis, 4–9 cm. lat breviter acuminatis vel subacutis, basi acutis v paullo decurrentibus; nervis primariis utrinq circiter 10, utrinque subaequaliter leviter elevat arcuato-anastomosantibus, secundariis pau minus distinctis, reticulis ultimis utrinque levit elevatis, subconfertis; petiolo 1–2.5 cm. long inflorescentiis terminalibus et in axillis superio

bus, 1–4 cm. longis, cymoso-paniculatis, pedunculatis (pedunculo circiter 1 cm. longo), vel e basi ramosis, ramis primariis paucis racemose dispositis; floribus 5-meris, sessilibus, trinis, bracteis oblongo-ovatis, acutis vel acuminatis, circiter 3 mm. longis, bracteolis similibus, paullo brevioribus; sepalis obovatis, late rotundatis, circiter 3 mm. longis, in sicco pallidis, subreticulato-rugosis, margine membranaceis; petalis subellipticis, sepala aequantibus, rotundatis; filamentis vix 1 mm. longis, disci margini insertis; ovario anguste oblongo-ovoideo, obscure sulcato, 2-loculari.

BORNEO: British North Borneo, Mount Kinabalu, Tenompok, 1500 m. alt., *Clemens 29518*, Jan.-June, 1932, without notes (A holotype, B, Ge, L, N, UC).

59a. **Microtropis kinabaluensis** var. **acuminata** var. nov.

A typo differt foliis tenuioribus, angustioribus, perspicue acuminatis, 13–17 cm. longis, 3–6 cm. latis; fructibus ellipsoideis vel subcylindraceis, 12–15 mm. longis, breviter apiculatis, rubris.

BORNEO: British North Borneo, Mount Kinalabu, Gurulau Spur, *Clemens 10844* (M); Penibukan, *Clemens 31504* (B, L, N), 40579 (A holotype, L, UC), an undershrub, alt. 4500–5000 ft. Some of these specimens have mature fruits, red when ripe, ellipsoid to somewhat obovoid, about 1.5 cm. long.

It is possible that what we have placed as a variety of *Microtropis kinabaluensis* may ultimately prove to be worthy of specific rank. The material available is somewhat inadequate. It is suspected, however, that the differences indicated may possibly be due to varying habitats. It is varyingly described as a "small tree" and as an undershrub less than 2 feet high. The species is manifestly allied to *Microtropis sterrophylla*, but has much thinner leaves, the primary and secondary nerves and the ultimate reticulations being more or less elevated and distinct on both surfaces.

60. **Microtropis sterrophylla** sp. nov.

Frutex circiter 1 m. altus, glaber, ramis ramulisque teretibus, rigidis, rubro-brunneis, novellis interdum subcompressis, junioribus 3–4 mm. diametro; foliis crassissime coriaceis, rigidis, 12–15 cm. longis, 3–6 cm. latis, lanceolatis vel oblongo-lanceolatis vel subellipticis, utrinque subaequaliter angustatis, basi cuneatis, apice perspicue acuminatis, margine revolutis, supra olivaceis vel olivaceo-viridibus, subtus valde pallidioribus subalbicantibus; nervis primariis utrinque 10–12, subtus obscuris; inflorescentiis axillaribus, cymoso-paniculatis circiter 2 cm. longis, plerumque solitariis, ut videtur paucifloris (floribus haud visis), pedunculo 1–1.5 cm. longo; rhachibus supra ramos primarios inferiores productis, ramis primariis paucis, crassis, circiter 7 mm. longis; fructibus immaturis subcylindraceis, circiter 1 cm. longis, apiculatis.

BORNEO: British North Borneo, Mount Kinabalu, Penibukan and Nienkok, *Clemens 31504* (A, type), *30773*, (A, N, B), s. n. (B), on forested slopes 900–1500 m. alt.

A species in the general alliance with *M. kinabaluensis* Merr. & Freem. characterized, however, by its rigid stout branchlets and its very coriaceous, rigid leaves (whence its specific name) which are very pale, often almost white beneath when dry.

61. **Microtropis rubra** Elmer in herb. sp. nov.

Frutex glaber, ramis teretibus, brunneis vel rubro-brunneis, ramulis teretibus leviter compressis vel obscure sulcatis, ultimis, 1.5–2 mm. diametro, internodiis 3–11 cm. longis; foliis chartaceis, ellipticis vel elliptico-ovatis, breviter vel graciliter acute acuminatis, basi late acutis vel decurrenti-acuminatis, 8–14 cm. longis, 4–8 cm. latis, supra pallide olivaceis, subtus pallide brunneis, nervis primariis utrinque 7–8, gracilibus, utrinque leviter elevatis, arcuato-anastomosantibus; petiolo 8–10 mm. longo; inflorescentiis axillaribus, solitariis, paniculato-cymosis, i. e. rhachibus supra ramis primariis distincte productis, 1–2 cm. longis, paucifloris; floribus 5-meris, circiter 2.5 mm. longis, plerumque binis vel trinis in ramulis ultimis dispositis, lateralibus breviter (1 mm.) pedicellatis; bracteis ovatis, acutis vel acuminatis, circiter 1.5 mm. longis, bracteolis similibus, brevioribus; sepalis late ovatis, rotundatis, 2–2.2 mm. longis, margine integris; petalis (immaturis) ellipticis, 2 mm. longis; staminibus 5, margini disci distincti (0.8 mm. alti) insertis; filamentis crassis, brevibus, antheris ovoideo-ellipticis, 0.6 mm. longis; ovario 2-loculari, angusto, cum stylo obscure sulcato 2 mm. longo; fructibus oblongo-ellipsoideis, perspicue rostratis, circiter 2 cm. longis, ad 8 mm. diametro, rostro angusto, plerumque 5 mm. longo.

PHILIPPINES: Luzon, Sorsogon Province, Irosin, Mount Bulusan, *Elmer 14367* (A holotype, Ge, Gr, L, N, U, UC), *15669* (A, Ge, Gr, L, N, U, UC), April, 1916, without notes.

This species was distributed by Mr. Elmer under the specific name we have adopted. In 1923 it was cited, *in nota*, by Merrill, Enum. Philip. Fl. Pl. **2**: 482. 1923 under *M. philippinensis* Merrill, which had been described from a Catanduanes specimen in 1918. A more critical examination of the material available clearly indicates that two distinct species are represented, *M. philippinensis* Merr. with strictly dichotomous cymes, and *M. rubra* Elmer with paniculate-cymose inflorescences. Both species, however, have relatively large prominently rostrate fruits. They differ further in vegetative characters, *M. philippinensis* Merr. having oblong-elliptic, relatively narrower leaves than *M. rubra* Elm. We suspect that Mr. Elmer selected the specific name either because of the red fruits of his species (no notes available), or because of the sometimes slightly reddish tinge to the pale brown lower surfaces of some of the leaves when dry. In one specimen of *Elmer 14367* examined, the uppermost reduced cyme was dichotomous rather than paniculate-cymose.

62. **Microtropis basilanensis** sp. *nov.*

Frutex circiter 2 m. altus, glaber; ramulis 1–2 mm. diametro, novellis 4-angulatis, sulcatis, pallide brunneis, internodiis 5–7 cm. longis; foliis chartaceis, vel junioribus submembranaceis, late oblongis vel oblongo-ellipticis, graciliter acuminatis, basi acutis vel leviter decurrentibus, 12–17 cm. longis, 4–7 cm. latis, supra olivaceis vel cinereo-olivaceis, leviter nitidis, subtus pallidioribus, pallide rubro-brunneis; nervis primariis utrinque circiter 10, subtus magis distinctis, reticulis ultimis supra obscuris, subtus distinctis; petiolo gracili, 1–1.5 cm. longo; cymis axillaribus et extra-axillaribus, paniculato-cymosis, circiter 1.5 cm. longis, plerumque solitariis, pedunculo 1 cm. longo, rhachibus supra ramos primarios productis; floribus paucis, 4-meris, immaturis, plerumque sessilibus, in triadibus dispositis, bracteis 2 mm. longis, pallidis, minute erosis; sepalis elliptico-ovalis, rotundatis, circiter 2 mm. longis, pallidis, erosis; petalis immaturis quam sepala brevioribus; staminibus disci margini insertis; ovario ovoideo, sursum angustato, 2-loculari.

Philippines: Basilan, Mount Basilan, *Miranda 18930* (M, U, photo. A), near small streams in forests at 400 m. alt.

This species in general resembles several other of the large leaved Philippine forms, notably *M. platyphylla* Merr., *M. chartacea* Merr. & Freem., and *M. philippinensis* Merr., differing in its 4-merous flowers and in its vegetative characters.

63. **Microtropis rostrata** Merr. Philip. Jour. Sci. **17**: 275. 1920, Enum. Philip. Fl. Pl. **2**: 482. 1923.

Philippines: Luzon, Camarines Province, Paracale, *Ramos & Edaño 33568* (A, L, M, U); Alabat, *Ramos & Edaño 48070* (M, N, UC), *48164* (A, M, N, U, UC).

This resembles *M. fasciculata* Quis. & Merr., but can easily be distinguished from it by its smaller, narrow, acuminate leaves and peduncled cymose-paniculate inflorescences. It also somewhat resembles *M. philippinensis* Merr., but differs in having elongated, sublanceolate leaves, more numerous lateral nerves and more prominently rostrate fruits, as well as in its cymose-paniculate rather than strictly dichotomous inflorescences.

64. **Microtropis platyphylla** Merr. Philip. Jour. Sci. Bot. **10**: 319. 1915, Enum. Philip. Fl. Pl. **2**: 482. 1923.

Philippines: Luzon, Rizal Province, Montalban, *Loher 5774* (M, photo. A), *5779* (U, photo. A), *12853* (UC, M), *14251* (M); Balintingan *13882* (A, M); Mount Irig, *Ramos 41898* (A, M, U).

64a. **Microtropis platyphylla** Merr. var. **ellipticifolia** var. nov.

A typo differt foliis minoribus, ellipticis, plerumque 8–14 cm. longis, 4–8 cm. latis.

Philippines: Luzon, Nueva Ecija Province, Mount Umingan, *Ramos & Edaño 26402* (A type, M, N, U); Tayabas Province, Mount Alzapan, *Ramos & Edaño 45674* (M, UC); Mount Binuang, *Ramos & Edaño 28569* (A, M, UC). A small shrub about 1 m. high in forests.

Excluded species

Microtropis ? coriacea Wall. List no. 4338. 1830, *nomen nudum;* Ettingsh. Denskr. Akad. Wiss. Wien. Math.-Nat. Classe **13**: 64. *t. 4. f. 12.* 1857, descr. fol. = *Salacia flavescens* Kurz.

The Index Kewensis reduction of this species is to *Gynotroches axillaris* Blume, apparently due to a remark made by Arnott, Ann. Nat. Hist. **1**: 372. 1838, to the effect that *Microtropis coriacea* Wall.,

of which he had seen no flowers, was probably the same as *Dryopetalum coriaceum* Arn. = *Gynotroches*. This erroneous reduction is repeated in Hook. f. Fl. Brit. Ind. **2**: 440. 1878, although three years earlier Lawson, op. cit. **1**: 625. 1875, had correctly reduced it to *Salacia flavescens* Kurz. We are indebted to Mr. Gilmour of the Royal Botanic Gardens, Kew, for a loan of *Wallich 4338*, and to Mr. Airy-Shaw for a critical note on problems of nomenclature involved.

MICROTROPIS LANCEOLATA Boerl. & Koord. in Koord.-Schum. Syst. Verzeich. Herb. Koord. **2**: 33. 1911 = *Linociera* sp.

This species was based on *Koorders 10283* β, Yzerman Expedition to central Sumatra, a fruiting specimen. Examination of the holotype in the Buitenzorg Herbarium clearly shows that a species of *Linociera* perhaps allied to the Bornean *L. oligantha* Merr. is represented. I have not been able to match the specimen to my satisfaction among the Malaysian species of *Linociera* available to me, nor was Dr. Van Slooten any more successful at Buitenzorg.

MICROTROPIS LATIFOLIA Gardn. ex Bedd. Trans. Linn. Soc. **25**: 213. 1865, *nomen nudum*.

This is probably the species later described by Gamble as *Microtropis Stocksii* Gamble. Gardner's binomial was based on a specimen from the Anamalai Mountains in India. The other possibility is *Microtropis latifolia* Wight.

AMERICAN SPECIES

As noted in the introduction, we have not studied the few American species as these have been considered by Sprague, Kew Bull. 362–364. 1909, and very recently again by Dr. C. L. Lundell. The latter's paper with amplified descriptions of the four species and an analytical key, appears in Contr. Herb. Univ. Michigan **3**: 23–35. 1939. The species are merely listed here as Dr. Lundell has disposed of them.

MICROTROPIS GUATEMALENSIS Sprague, Kew Bull. 364. 1909. Guatemala.

MICROTROPIS OCCIDENTALIS Loesen. Bot. Gaz. **24**: 393. 1897. Mexico: Vera Cruz.

MICROTROPIS SCHIEDEANA Loesen. Bot. Jahrb. **29**: 98. 1901. Mexico: Vera Cruz.

MICROTROPIS STANDLEYI Lundell, Bull. Torr. Bot. Club **65**: 463. 1938. Costa Rica.

EXCLUDED AMERICAN SPECIES

MICROTROPIS FILIPES Sprague, Kew Bull. 363. 1909 = *Myginda filipes* (Sprague) Loesen. Notizbl. Bot. Gart. Berlin **13**: 226. 1936. Mexico: Tobasco.

MICROTROPIS PARVIFLORA Sprague, Kew Bull. 363. 1909, based on *Euonymus parviflorus* Hemsl. Diagn. Pl. Nov. **1**: 6. 1878, Biol. Centr.-Am. Bot. **1**: 188. 1880 = *Myginda ? parviflora* Loesen. Notizbl. Bot. Gart. Berlin **13**: 225. 1936 = *Rhacoma parviflora* (Hemsl.) Lundell, Am. Midl. Nat. **20**: 238. 1938. Nicaragua.

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INTERATOMIC FORCES AND HELIUM IN ROCKS

By Norman B. Keevil[1]

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Introduction

In the problem of determining the geologic ages of rocks by the helium method, the question of the fate of the helium atom is of paramount importance. The method itself seems to have been proven by the past few decades of research in the physics and chemistry of radioactive phenomena, and accordingly the validity of the principles upon which it is based, and the uniformity of its mechanism, are now quite generally accepted. All experimental attempts to hasten or retard the rate of disintegration by bombardment with cosmic rays, by subjecting the materials to pressures up to 20,000 atmospheres, or by heating them up to 3,000° C. have been without effect; and accurate photometric measurements of pleochroic haloes have shown that the rate has been uniform throughout all geologic time. Recently, the agreement obtained between the values of the "activity index"[2] of rocks determined by two entirely different methods[3] has offered further evidence for the reliability of radioactive theory and the accuracy of the physical constants involved. The activity index is calculated, in one method, from separate measurements of radon and thoron, using the disintegration constants and assumptions of radioactive equilibria for the three known radioactive series uranium, actino-uranium, and thorium, while in the other it is found independently of assumptions by a direct alpha particle count from a thin deposited film of the rock.

To complete the experiments necessary for a computation of geologic age, it is required to know the number of helium atoms emitted since the radioactive elements were sealed up by crystallization. When this number is calculated from the determination of the present helium content of rocks, it is assumed that no helium has escaped, and this is by no means well established. The opinion is prevalent that helium, being a light element and gaseous, should be able to diffuse through rocks during geologic time, and this receives some apparent support from the permeability of glasses to helium, and its escape from radioactive minerals. But in the former instance the diffusion can be shown to occur through relatively large channels, not present in crystals, while in the latter, it is due to the generation of up to a million times the quantity of helium found in ordinary rocks, and its consequent escape under higher internal pressures through badly disrupted crystal structures. Statements are sometimes made that helium should be able to diffuse through certain kinds of crystals because of their open structure, but these appear to be guesses made without any quantitative picture of the situation.

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[1] Paper No. 52. Published under the auspices of the Committee on Geophysical Research and the Division of Geological Sciences at Harvard University.

[2] Activity index = total alpha particle emission per milligram of sample per hour.

[3] Evans, Goodman, Keevil, Lane, and Urry, Phys. Rev., *55*, 931–946 (1939).

The exact analysis of this problem involves a knowledge of the spacings within the crystal, their regularity and permanence, and the dimensions of the helium atoms with respect to these; it requires also a knowledge of the degree of crystal imperfection caused by peculiarities of crystal growth, or by radioactive disintegrations and later stresses. Some of these questions can be answered by experiments in the laboratory, and some insight into the problem can be obtained from a consideration of its theoretical aspects.

Experimental determinations of atomic dimensions have shown a considerable variation in size for any one atom, depending on the method of measurement and the type of compound, but for a given environment the size is essentially constant. The effective sizes of atoms and other dimensions of crystal structures, determined accurately by X-ray and other methods, are used below for a comparison of the interatomic spacings in minerals with the effective size of the helium atom. There are a number of experimental values of the atomic radius of helium, but none of these has been determined for the type of environment found in crystals, In order to find whether the effective size is much different, it is necessary to analyze the nature of the interatomic forces involved, and to determine their effect on the helium atom. This is simplified somewhat by the similarity of most common rock minerals, which are essentially close-packed networks of oxygen ions. The problem is treated by combining theoretical and experimental parameters for the calculation of the force relations between a helium atom and a crystal atom or ion, followed by a simple extension to the three-dimensional environment within minerals and glasses, and by a discussion of helium diffusion experiments on various substances. After a comparison of the size of the helium atom with the spatial dimensions of common minerals and glasses, and calculations of the extent of self-diffusion through crystal structures during geologic time, the effect on helium retention of other factors such as crystal imperfections, compound formation, radioactive disruptions, and possible loss through interstices is discussed.

Before entering into the details of calculation, it seems appropriate to include a review of the modern picture of atoms, and the several ways in which they may combine to form molecules, and to illustrate the use of potential energy curves in analyzing interatomic forces. The discussion is quite general and descriptive, without the usual mathematical approach, since it is intended primarily for the geological reader. The phenomenon of diffusion in minerals and rocks is of the utmost importance to geology, but little fundamental research of either a theoretical or an experimental nature has yet been carried out. In some instances, diffusion has been attributed to the permeability of the atomic networks of the minerals themselves. To investigate this possibility, the simplest approach is first to study the behavior of the smallest inert gas atom in crystals and glasses, and later to make further extensions, and to attack more complex systems. While the primary purpose of this paper is to examine the diffusibilities of helium in rocks and minerals in their relation to the helium age problem, the new methods and results may be applicable to other geological phenomena involving forces in crystals, such as adsorption and replacement processes and certain ore-genesis problems; this has been borne in mind in reviewing all past work on the diffusion of helium, and in the general scheme of presentation of the paper.

I. REVIEW

The Modern Picture

With the advance in our understanding of its physical nature, the picture of the atom has progressed from the hard spherical ball type of the late nineteenth century to the nebulous electrical model of today. While we are unable to see an atom, we can obtain a vague mental picture, and an exact mathematical one which is consistent with its known behavior and is useful in predicting its reaction to new environments. The different kinds of forces between atoms can be distinguished and evaluated, and the atomic dimensions calculated within narrow limits. The outer part of the atom may be pictured as a mobile cloud of electrons distributed according to certain physical laws around a positively charged nucleus, and increasing in density towards the centre (Fig. 1a). The mass of the atom is concentrated in the nucleus, which occupies a negligibly small part of the volume. All that theory can tell us about the position of any one of the extra-nuclear electrons is the probability of its being at a certain spot at any one moment. The instantaneous picture is then a rather nebulous and indefinite sort of thing.

When any neutral atom or molecule is near another, there are always attractive forces acting between them because of the interaction of their nuclei and their electrical atmospheres, and these operate even in a tenuous gas. Of course, such an attraction does not become appreciable until the particles come close together. Then, owing to the energy and velocity distribution, it may effect only a transitory union, or owing to suitable energy and orientation factors it may result in the formation of a molecule. These attractive forces are generally sufficient to cause an interpenetration of the electrical atmospheres at the periphery of atoms. The amount of penetration, however, is limited by a second force arising from the repulsion of the nuclei and the electron atmospheres, and this rapidly becomes more important as the penetration increases. How close the atoms can approach under a given set of conditions depends upon the contributions of these attractive and repulsive forces. The final state of equilibrium is a result of the sum of these effects.

The distance of nearest approach defines the dimensions of the particle. It can be determined experimentally for certain substances and may also be calculated theoretically in some cases from a consideration of the forces of interaction. It is obvious that a diameter determined from an experimental observation or from some theoretical calculation is an interatomic distance valid only for the particular conditions under which it was determined. In an experiment measuring the nean distances between molecules in gases, it is a statistical average diameter for an assumed pherically symmetrical model; for similar atoms t is the average distance between the centres of wo atoms in contact. In some atoms the effecive radii may vary enormously, depending on the nvironment and the type of binding as illustrated ı Fig. 1b for chlorine, but, as shown later, in thers such as helium and the remaining inert ases, the size is relatively constant.

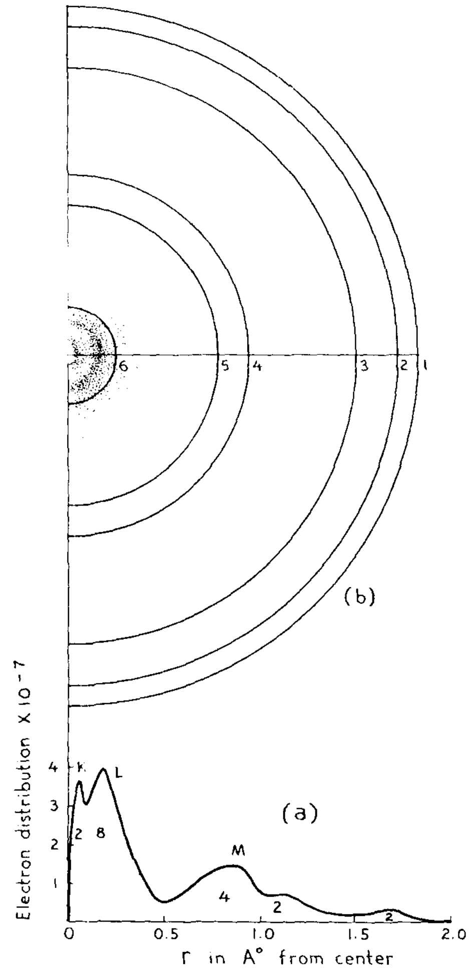


FIGURE 1. a) The electron distribution, $D = 4\pi r^2\rho$, (where ρ is the electron density), as a function of r (radius in Ångstrom units, or 10^{-8} cm.) for the chloride ion. K, L, M refer to shells of electrons, the numbers beneath the curve to the number of electrons in that range of r.

b) The size of chlorine in different environments: 1 and 2 are ionic radii, Cl^-; 4 is the valence radius; while 3 is an intermediate type as in AgCl; 5 is the radius of normal chlorine; 6 is that given by Pauling for perchlorates, Cl^{7+}. The chlorine nucleus is the same in each case, but the electron atmosphere, which determines the size of the atom, is different. For any one kind of particle the size is found to be the same within fairly narrow limits, e. g., Cl^- between 1 and 2.

The closest distance of approach of any particular system of atoms is that encountered in their stable molecular form at absolute zero (− 273.1° C.). At this temperature the atoms are in their lowest energy state, vibrating with small amplitudes. If we fix our attention on a sodium ion in the network making up a sodium chloride crystal, it will be vibrating with respect to all six of the chlorine ions with which it is surrounded. Each of these chlorine ions is in turn surrounded by six sodium ions, and oscillating with respect to all of these, and so on. All of these vibrate over a limited range of amplitudes and frequencies, so that the entire crystal may be pictured as continuously oscillating over very small displacements. When the energy increases to a certain point with rising temperature, some of the atoms begin to vibrate over larger displacements, so that the symmetry and periodicity are suddenly destroyed. This means that the system has passed over to the liquid state of aggregation. That the actual displacements are not great in the crystal, and change only slightly with temperature, may be shown by calculation from specific heat data, and by allowing certain light rays to fall upon the crystal and studying the reflection or spectrum. If the wave length of the light (X-rays) is of the order of 10^{-8} cm., that is, of the order of atomic dimensions, the rays are diffracted by the regular rows of atoms in the crystal, just as visible light is diffracted by a spectroscopic grating. The fact that the reflected beams are very regular both in direction and intensity proves the regular order of the atomic distribution within the crystal, and the absence of large displacements. It is possible to determine the atomic pattern of the crystal from the wave length of the X-rays employed, the angle and the intensity of the reflected beams, the density, and the chemical analysis.

The amplitudes of vibration and distances of separation are greater in liquids, but not much different from those of the crystal. The interatomic or interionic distances are changed only slightly and the presence of similar regular but more mobile groupings is shown by X-ray analysis. The change from liquid to gas is quite a different matter; the molecules are no longer in close contact, and the effective diameter and the mobility are both increased. In our present problem we are concerned with the interatomic distances in crystals, determined by X-ray analysis, and with the size of the gaseous helium atom relative to these.

The Forces between Atoms

The attractive forces operating between atoms may conveniently be divided into two kinds, (1) those that are responsible for molecule formation, and (2) those weaker forces that are responsible for the deviations in the pressure-volume relations of gases from the perfect gas law, and which operate to hold the molecules together as liquids and solids at lower temperatures. The first, those attractive forces that result in chemical binding, are usually again divided into four types: ionic, valence, metallic, and van der Waals forces. The distinction between these is sometimes difficult to make, and one more of degree than of kind. Thus, the bonds in silicates are intermediate between the ionic and valence types. The interatomic distances found from X-ray analyses may be employed to distinguish between covalent, or valence, bonds and ionic bonds. For example, in Fig. 1b, the outer radius is that of chlorine in typical ionic compounds like NaCl, while 0.99 Å* is that found in the valence bond between atoms in the chlorine molecule. The radius of Cl in AgCl is 1.6 Å, and the bond is therefore an intermediate type, although more ionic than covalent.

The van der Waals type is the weakest molecular binding force and may also come under the second main class above, for it operates between all molecules and may or may not result in molecule formation, depending upon the valence conditions. Chemically it occurs only in certain large, easily dissociated molecules such as complex organic compounds, and in adsorption and diffusion phenomena in crystals. It is the kind of interaction with which we are most concerned in this paper. It is named from its relation to the correction factor "a" for intermolecular attraction in the van der Waals equation of state for gases,

$$(p + a/v^2)\ (v - b) = RT \ldots\ldots (1)$$

an important equation, for from the pressure (p), volume (v), and temperature (T) measurements of gases, a knowledge of the attractive force (a) and the volume of the molecules (b) can be obtained. R is the gas constant.

Potential Energy Curves

To understand the forces that are operating between atoms in crystals, it is convenient tc picture them as arriving at their present positior as a molecule, or as a crystal unit, in the following way. Originally the atoms or ions are separatec at an infinite distance. Here the potential energ of the system Na^+ and Cl^-, for example, is takei as zero. As the ions come closer together, th attractive force, electrostatic attraction in thi case, results in a decrease of the potential energ of the system as shown by *AB* in Fig. 2. The change in energy can be calculated from the expression:

---

* 1Å = one Ångstrom unit = 10^{-8} cm.

$$E = \frac{-\alpha z^2 e^2}{R} \qquad \ldots\ldots\ldots\ldots (2)$$

where α = a constant, z = charge on the ion, e = elementary charge, 4.80×10^{-10} e. s. u., and R is the distance between centres. As the ions approach each other, the attractive force increases rapidly (*BC*), until finally the repulsive force between the nuclei begins to enter (*C*). This becomes rapidly more important due to its dependence on a greater power of *R*. The potential

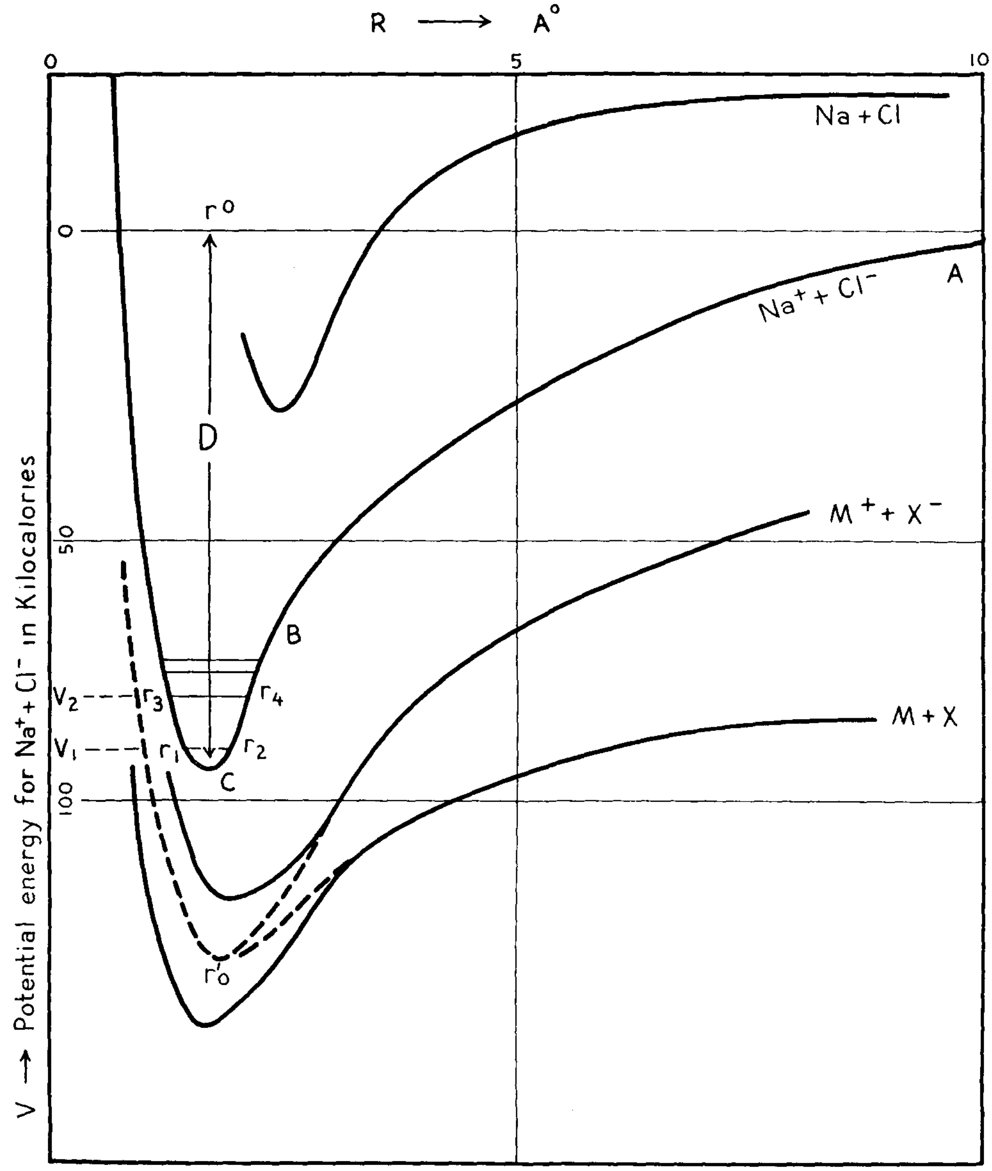


FIGURE 2. Potential energy curve for diatomic molecules. Potential energy, V, as a function of interatomic distance, R. The upper curve is a hypothetical case for covalent NaCl; the second, the actual curve for NaCl, to which the energy units refer. The lower curve illustrates the resonance energy effect between the ionic and covalent structures which results in an intermediate type bond, shown by the dotted line. D represents the energy of dissociation, r_0 and r_0' the equilibrium distances of separation, and r_1–r_2, r_3–r_4, etc., amplitudes of vibration for different vibrational energy levels.

energy V, for this ionic type of binding is given approximately by:

$$V = \frac{-\alpha z^2 e^2}{R} + \frac{B}{R^n} \quad \ldots\ldots\ldots\ldots (3)$$

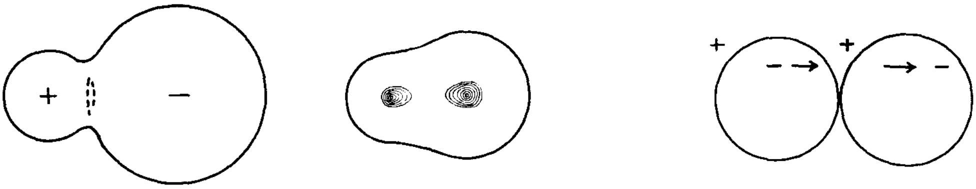
where B/R^n is the repulsion term, B is a constant, and n is about 9 for many substances.

The behavior of such a system has been illustrated by the analogy of a rolling ball in a trough where the system is represented by a ball at height A (Fig. 2), falling under the influence of gravity, oscillating or rolling back and forth in the trough BCr_3, and finally coming to equilibrium at r_0.

The equilibrium distance of separation in the normal molecule is that configuration giving the minimum potential energy to the system. Referring to Fig. 2, this distance is at r_0, which is the sum of the radii of the two particles, Na^+ and Cl^-. The energy necessary to separate the ions to infinity, or the heat of dissociation, is given by D. Vibration in the crystal at energy V_1 occurs over the range r_1 to r_2, while at energy V_2, the amplitude of vibration is from r_3 to r_4, and so on. The number of higher energy levels and the amplitudes of vibration increase with temperature.

The valence type of chemical binding force may be interpreted similarly with potential energy curves. Such bonds almost invariably consist of a shared pair of electrons common to both atoms, and only rarely are links formed through one or three electrons. If upon attraction the valence conditions are suitable, electron exchange occurs between the atoms at short distances, resulting in the electron pair bond. The conditions for the formation of this type of molecular link are that both have an incomplete outer shell of electrons, and that one of these have an electron spinning in one direction, while the other have an electron with a spin in the opposite direction. Then the resultant effect is a coulomb attraction somewhat analogous to that acting between two opposite pole magnets, and the two form a pair of electrons in an orbit common to both atoms. Diagrammatic representations of the different types of binding are given in Fig. 3. The shape of the potential energy curves, and hence the position of R_0, for the different kinds of interaction will vary, since the forces are dependent on different powers of R.

The possibility of a covalent bond for sodium chloride has been excluded on energy considerations.[4] The potential energy curve of such a system is given in Fig. 2. (The difference in energy between atoms and ions results in different energy levels for infinite separation.) From the two curves, it will be observed that the ionic bond is stronger because such a system has a lower potential energy level, and a smaller atomic separation at equilibrium. The separations between the two types of potential energy curves may be small in some cases as MX and M^+X^- in Fig. 2. A so-called resonance may then occur between the two, giving a stronger bond than either. The resultant potential energy near the minimum is represented by the dotted line, with an equilibrium interatomic distance of r_0'. Such cases are quite common, and there may be all types of gradation from the purely ionic to the purely covalent bond between atoms.



Ionic Bond

Covalent Bond

Polarization attraction

FIGURE 3. Diagrammatic representations of bond types.

Attraction without Stable Molecule Formation

While on the average an atom is spherically symmetrical, at any one instant this is not necessarily true. The electrical atmosphere is continually changing, and fluctuating in its effect on neighboring atoms. There results a van der Waals interaction between these rapidly moving electron systems, due to their tendency to move in phase with one another. There may be an instantaneous separation of charge giving a dipole moment, and this will form a dipole on a neighboring atom, which may induce one back on the first, and so on. Such induced polarization results in an attraction, as illustrated in Fig. 3c. The amount of interaction, and similarly the distance of approach, depends upon the polarizability, α, which is roughly proportional to volume, i. e., $\alpha = KR^3$. Such polarization molecules have a low heat of dissociation, and only a transitory existence. This means that the attractive forces are small, and the repulsive forces become important at greater distances of separation. The "troughs" of the potential energy curves are quite shallow, and thermal agitation supplies sufficient energy to dissociate the "compound" almost immediately. This is the type of situation that would be expected in the interactions of helium and the other inert gases. In addition to this first order effect, there will be an interaction when the atom or molecule is in the vicinity of an ion. This second order perturbation or polarization force results in an attraction which is greater than that resulting from the dynamic interaction of two neutral atoms.

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[4] Pauling, J. Am. Chem. Soc. *54*, 997 (1932).

Activation Energy

It is commonly observed that before some physical or chemical process can occur, a certain critical energy is required. This is known as the activation energy, E. Before a chemical reaction can take place in fluids, for example, the molecules must have at least a certain minimum kinetic energy, and in the case of diffusion through a solid a similar activation energy must be possessed before the particle in question can pass through. The analogy previously used of a rolling ball in a trough or valley (Figs. 2, 12a, 14), of minimum potential energy may be used. Before the reaction can proceed, that is, before it can leave this "valley," it must cross over a barrier or through a pass to another valley of lower potential energy representing the end state. Only atoms having enough energy, or in our analogy, only those balls moving fast enough to mount the pass can reach the second state. The difference in elevation between the pass and he valley represents the activation energy. In a gas, the fraction of the atoms having an energy greater than E is given by the distribution law or velocities and energies as,

$$e^{-E/kT}$$

where k is the Boltzmann constant $= 1.37 \times 10^{-16}$ erg per degree, and T is the absolute temperature.*

Atomic Sizes

The mass of the atom is concentrated in the nucleus, and while it occupies a negligible volume, it indirectly governs the volume of the external field of electrons by its residual charge. While the atoms and ions have no rigid boundary, for any one kind of environment it is observed that the particular kind of repulsive force increases abruptly at a certain distance. This governs the closest distance of approach, and in this sense, the atoms or ions may be treated as spheres in contact. Now in common rock minerals, the environments are similar, and each ion exhibits a more or less characteristic "size", so that interatomic distances can be obtained additively from the radii of each pair of ions, and these are in close agreement with most distances determined experimentally by means of X-rays.

A number of common atomic and ionic sizes[5] are shown in Fig. 4. Since the radius effective in common minerals is that which is of most interest in geological problems, it is represented in each case by the heavy line. Any small variations from these sizes in any particular mineral can be found by reference to the X-ray investigations.[5e] In the silicates, the main framework of the crystal structure is governed by the different kinds of silicon-oxygen chains, the bonds in which are intermediate between the ionic and covalent types. In all of the silicate minerals thus far examined, the small silicon ion is surrounded by four oxygens at the corners of a tetrahedron. It is notable that the dimensions of these tetrahedra are nearly constant, the silicon-oxygen distance being about 1.6 Å, and the oxygen-oxygen distance 2.6 Å.

Silicon atoms are often replaceable by aluminum, the two being indistinguishable by X-rays.

---

* The expression for more complex molecules than diatomic need not concern us here. If E is expressed in calories per mole instead of in ergs per atom or molecule, then $k = 2$ cals./mole/degree, usually designated by R, the gas constant. In this paper, k and R are used interchangeably.

[5a] Goldschmidt, Norske Videnskap. Akad. Oslo (1924) and (1926) No. 2.

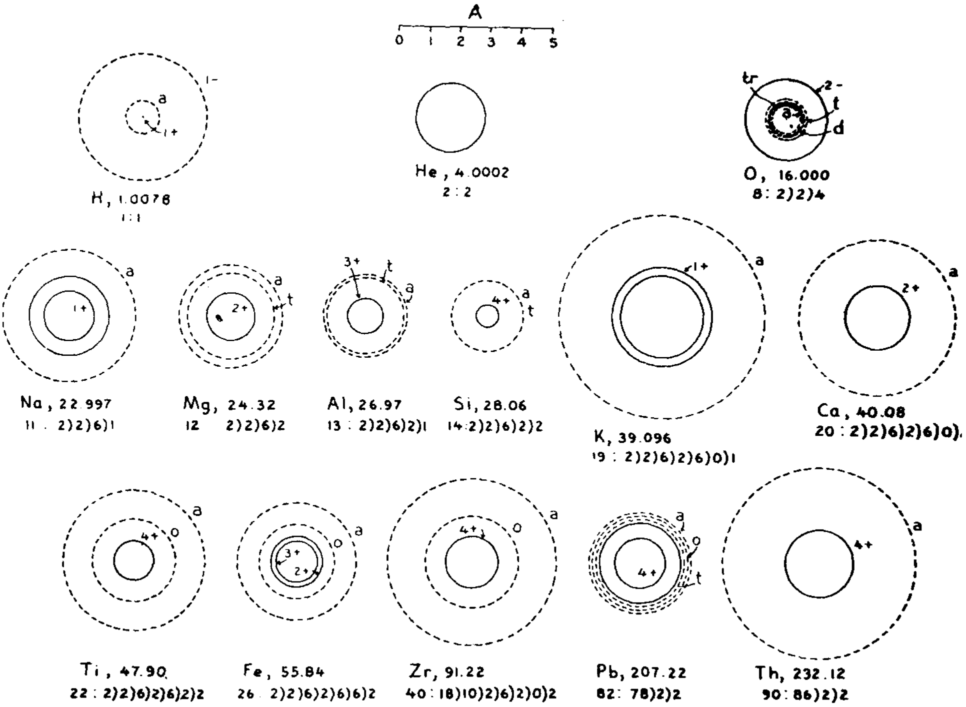
[b] Pauling, J. Am. Chem. Soc. *49*, 765 (1927).

[c] Slater, Phys. Rev. *36*, 57–64 (1930).

[d] Pauling and Huggins, Z. Krist. A. *87*, 205–238 (1935).

[e] Bragg, Atomic Structure of Minerals, p. 30 (1937).

[f] Zachariasen, Z. Krist. A. *80*, 137 (1931).


A
0 1 2 3 4 5
a
1-
1+
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1 : 1
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2 : 2
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O, 16.000
8: 2)2)4
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1+
Na, 22.997
11 . 2)2)6)1
a
2+
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Mg, 24.32
12 2)2)6)2
3+
t
a
Al, 26.97
13 : 2)2)6)2)1
4+
a
t
Si, 28.06
14:2)2)6)2)2
1+
a
K, 39.096
19 : 2)2)6)2)6)0)1
2+
a
Ca, 40.08
20 : 2)2)6)2)6)0)2
a
4+
o
Ti, 47.90
22 : 2)2)6)2)6)2)2
a
o
3+
2+
Fe, 55.84
26 2)2)6)2)6)6)2
a
4+
o
Zr, 91.22
40 : 18)10)2)6)2)0)2
a
o
4+
t
Pb, 207.22
82: 78)2)2
a
4+
Th, 232.12
90: 86)2)2

FIGURE 4. Sizes of common atoms and ions; beneath each is given the symbol, the atomic weight, the nuclear charge or atomic number, and the electron distribution in the various shells:

1s) 2s) 2p) 3s) 3p) 3d) 4s) 4p) 4d) 4f) 5s) 5p) 5d) 6s) 6p) 6d) 7s.

The size prevailing for atomic binding is denoted by *a*; for ions by their appropriate charges; for tetragonal bonds by *t*; for octahedral bonds by *o*; for double bonds by *d*; and for triple bonds by *tr*. The size of the atom most commonly exhibited in rock minerals is shown in all cases by the solid line.

In such cases, then, the chains are composed of oxygen tetrahedra around silicon and aluminum atoms. When the mineral contains alkali and metal ions, these may be pictured as filling in the holes or cavities in the structure as illustrated in Fig. 9. The bonds so formed are more ionic in nature, so that foreign atoms within such a crystal will not be surrounded always by so-called neutral atoms; the forces of attraction will be greater than the ordinary van der Waals force, being increased by the interaction with the partially ionic bond within the crystal.

II. THE SIZE OF THE HELIUM ATOM

Forces between Helium and Crystals

In analyzing the forces operating between a helium atom and a crystal, we shall first consider the attractive and repulsive forces at short distances between helium atoms, and between helium atoms and an isolated atom or ion, and construct potential energy curves. This will be followed by an extension to the more complex environments in crystals. While such curves can be calculated by the mechanics built up from the wave theory of light and matter for simple atoms, the calculations become less accurate and involve more assumptions as the atoms and molecules become more and more complex. The closest values are obtained by a judicious combinatio of theoretical calculations and experimenta parameters. The above problem, for example, i greatly simplified if either the effective radii o the energies of dissociation are known.

Polanyi[6] has pointed out that there is generall a parallelism between the adsorption potentia and condensibility, so that one may conclude tha the cohesive van der Waals forces between ga atoms and the cohesive forces of adsorption a of the same nature. This is most probably tru in the case of the inert gases and some oth neutral molecules such as nitrogen. To obtain a idea of the order of magnitude of these forces on crystal surfaces, and of the effective atomic radii involved, therefore, we may examine the experimental and theoretical results on the attractive forces in helium and other inert gases. The potential energy curves are shown in Fig. 5. None of these inert gases forms chemical compounds, the minima occurring at low potential energies and relatively large atomic separations. The dissociation energy of the weakly attracted helium polarization molecule is very low: 130 calories. This agrees with the calculated heat of sublima-

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[6] Polanyi, Trans. Far. Soc., *28*, 316 (1932).

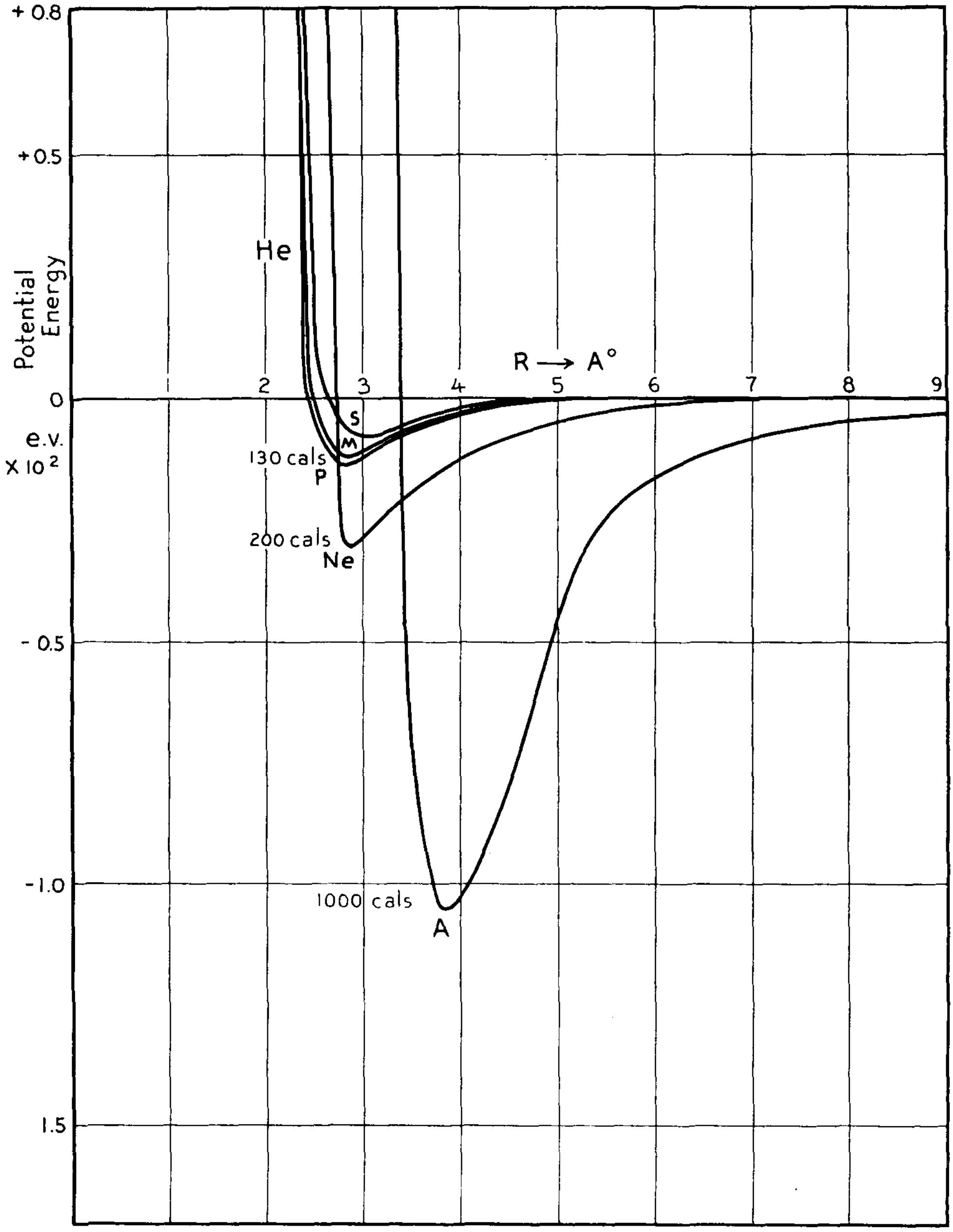


FIGURE 5. Potential energy as a function of interatomic distance for the inert gases. Curve *S* was calculated by Slater, *M* by Margenau, *P* by Page. For other calculations see Table II. 130 calories is the energy of dissociation for helium, 200 for neon, and 1000 for argon.

tion at 0° K.: 126 cals./g. mol.,[7a] and the experimental heats of adsorption of helium on nickel sulfate at 4.2° K.:[7b] 138 cals. The value of the equilibrium distance of separation is 2.85 Å, so that the effective radius is 1.42 Å, but at the point where the repulsive curve rises abruptly the value of R is 2.3 Å, and the radius 1.15 Å.

The attractive forces between helium and crystal elements may be expected to be a little greater than those between helium atoms themselves, due to the higher polarizabilities of many other atoms and ions. Lennard-Jones[8] has made some calculations of the interatomic forces between inert gas atoms and the surfaces of alkali halide crystals. In a potassium chloride crystal, both ions are treated as argon atoms, since they have the argon shell of electrons completed. A somewhat similar treatment is followed below, but some allowance is made for the difference in nuclear charge for these shells. The van der Waals attractive potential may be calculated using London's method,[9] based upon a second order perturbation treatment. This is done for helium and a few crystal ions in Figs. 6 and 7. The van der Waals interaction energy is given by:

$$w = -3/2 \frac{\alpha_{He}\,\alpha_x}{R^6} \cdot \frac{E_{He}\,E_x}{E_{He} + E_x} \quad \ldots\ldots(4)$$

where α_{He} is the polarizability of helium, $= 2.05 \times 10^{-25}$ cc.; α_x is the polarizability of the other atom or ion; E represents a summation of energy terms and is about equal to the first ionization potential, which is 24.465 e. v.* for helium; R is the interatomic distance between the centres of helium and the other atom, x. This gives the attraction part of the curves in Figs. 6 and 7, that corresponding to AC in Fig. 2. The values used for the interaction with oxygen ions, Fig. 6, were $\alpha_x = 3.5 \times 10^{-24}$ cc. and $E_x = 12.5$ e. v. If the oxygen in the crystal behaved more like a neon atom in its effect on foreign atoms, curves 2 and 5 would approach the shape and position of curves 3 and 4. But the repulsive side, which is the more important factor in later considerations, would be little changed. The results of a similar treatment for He and K are illustrated in Fig. 7; the values used were $E_x = 15.0$ e. v., and $\alpha_x = 0.85 \times 10^{-24}$ cc.

At short distances the repulsive force due to the entrance of nuclear repulsions after penetration of the electron atmospheres must be considered. The total effect is represented by the completed curves in Figs. 6 and 7, obtained from the equation:

$$V = -3/2 \frac{\alpha_{He}\,\alpha_x}{R^6} \cdot \frac{E_{He}\,E_x}{E_{He} + E_x} + \frac{b}{R^n} \quad \cdots(5)$$

Potential energy = Attractive + Repulsive
potential potential

The trend of the attractive term alone is shown by the dotted extensions of the curves. The repulsion term is of the form $C exp - k\left(\frac{r}{r_0}\right)$, or b/R^n. Both functions behave similarly, and for the present purpose b/R^n (where b and n are constants) is a satisfactory form to use. Values for n can be obtained from compressibility measurements; of the various values given,[5b, 8b, 10] $n = 9$, has been used.* The value of the dissociation energy for helium on certain crystal surfaces can be calculated[11] theoretically, and may be obtained also from the experiments by Frisch and Stern[12] on the reflection and diffraction of beams of helium atoms from crystal surfaces. Minima were observed in the curves from the plots of intensity of the reflected beam against the angle of reflection. The surface of a potassium chloride crystal, for example, has a periodic structure as far as adsorption of helium atoms is concerned (cf. Fig. 12a). These affect the beam like a cross-ruled grating. The two minima observed with the alkali halides are due to the two types of attractive potential loci at the alkali and halide centres. Since the halide is more polarizable, the greater heat of adsorption is that between helium and these ions. The experimental and calculated values obtained by Lennard-Jones and Devonshire are given in Table I.

[7a] Lennard-Jones, Proc. Phys. Soc. *43*, 474 (1931).

[b] Stout and Giaque, J. Am. Chem. Soc. *60*, 393–395 (1938).

[8a] Lennard-Jones and Dent, Trans. Far. Soc. *24*, 92 (1928).

[b] Lennard-Jones, Trans. Far. Soc. *28*, 333 (1932).

[9] London, Z. f. Phys. *63*, 245 (1930).

* e. v. = electron volts = 1.60 + 10^{-12} erg/atom/degree = 23,100 cals./mole/degree.

[10a] Born, Enz. Math. Wiss. V, *25*, p. 735, see ref. [5b].

[b] Herzfeld, Handbuch der Physik *22*, 454 (1926).

* Actually, if $n = 8$ or 10 the form and position of the curves shown are changed only slightly.

[11] Lennard-Jones and Devonshire, Proc. Roy. Soc. London *A156*, 37 (1936).

[12] Frisch and Stern, Z. Physik *84*, 430 (1933).

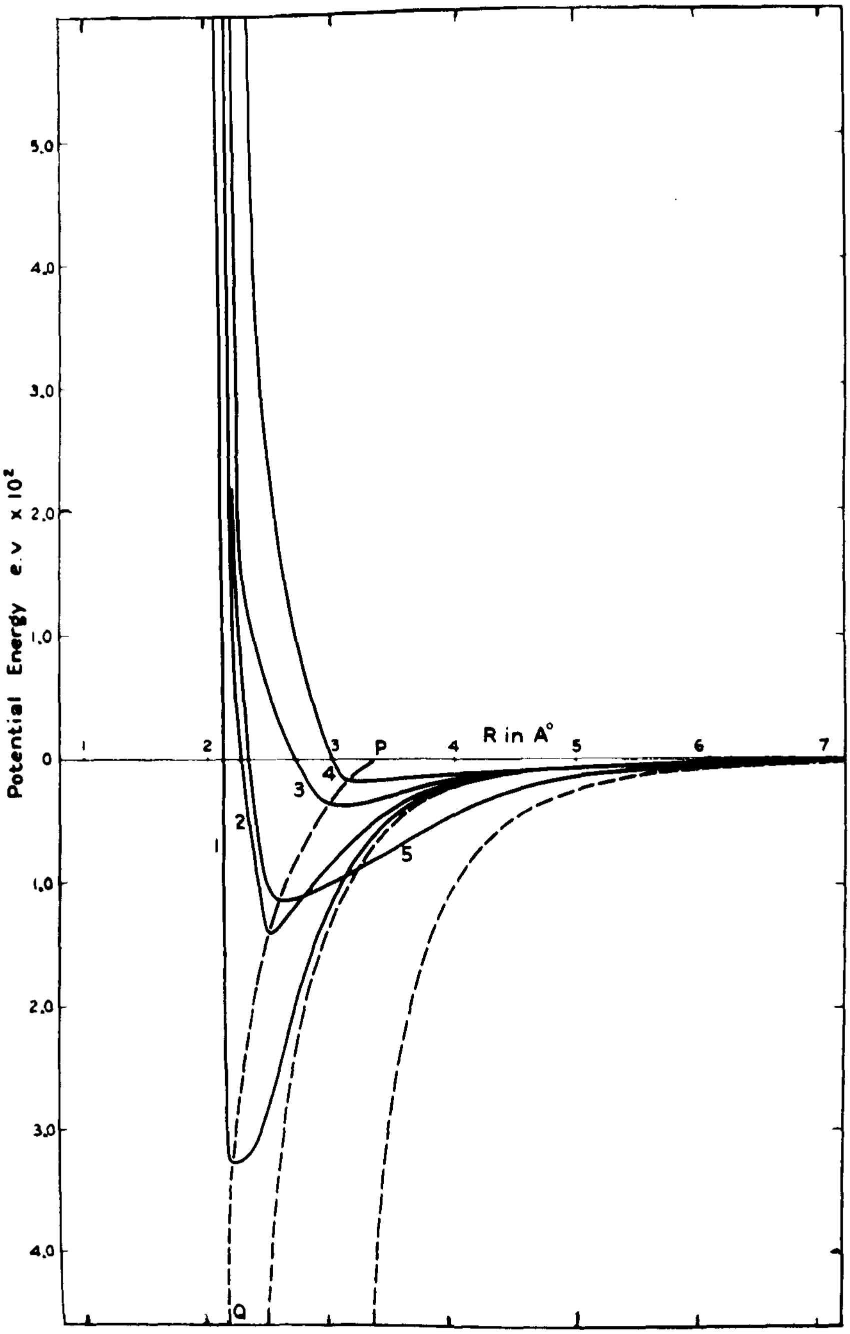


FIGURE 6. Potential energy curves for the system helium-oxygen. The variation of the attractive potential is shown by the two dotted curves to the right. The solid curves represent the resultant effect using different repulsive potentials. For curves 1, 2, 3, and 4 the values of b are 0.5, 1.0, 2.0, and 3.0 × 10^{-70} respectively. The trend of the minima with various assumed repulsive terms is shown by PQ; the upper part of the curve does not change appreciably. Curve 5 represents the resultant curve including both the van der Waals and the ionic polarization attractions.

TABLE I

HEATS OF DISSOCIATION OF HELIUM ON CRYSTALS

Crystal	Attraction Centre	Heat of Dissociation	
		From data of Frisch and Stern	Calculated by Lennard-Jones and Devonshire
LiF	Li +	57 ± 5 cals./mole	175 cals./mole
	F −	127 ± 5 cals./mole	
NaF	Na +	80 ± 5 cals./mole	267 cals./mole
	F −	193 ± 5 cals./mole	

From the results obtained between neutral helium atoms and between helium and alkali halide atoms in a crystal, the energy of adsorption of helium on crystals might be expected to have values ranging up to a little over 200 cals./mole., or up to about 0.01 electron volts. This fixes the position of the minimum of the potential energy curve, and thus provides values for the constant *b*, the interatomic separation, and the effective radius of helium.

The completed curve for the system He–K is given as curve 4, Fig. 7, while an approximate one for He–Si is given as curve 5, Fig. 7. The latter is not important for the present discussion because of the small size of the hidden silicon. In Fig. 6, curves 1, 2, 3, and 4 represent the curves for oxygen with values of b: 0.5, 1.0, 2.0, and 3.0 × 10^{-70}. The value chosen was 2.0 × 10^{-70} (curve 3).

In addition to the van der Waals forces, there may be other polarization forces entering into the attraction potential, because the bonds may have a residual ionic character. In silicates, the alkali and metallic atom links to the silicon-aluminum-oxygen chains are essentially ionic, and there may result some electrical asymmetry within the molecule; the helium atom will not be acted upon solely by neutral atoms, but will interact also with these partially ionic atoms. This polarization of the neutral atom by the electrostatic field of the crystal causes an induced attraction. The moment of the dipole produced is $\frac{\alpha z e}{R^2}$, where α is the polarizability, z = the charge on the ion, $e = 4.80 \times 10^{-10}$ e. s. u., and R is the internuclear distance. The potential energy of the attraction is given by:

$$w_p = \frac{-\alpha z^2 e^2}{2R^4} \quad \ldots\ldots\ldots\ldots(6)$$

The energy of helium and a singly charged ion has been calculated, using the same term as before for the energy of repulsion,

$$V = \frac{-\alpha z^2 e^2}{2R^4} + \frac{b}{R^9} \quad \ldots\ldots\ldots(7)$$

Curves 1 and 2, Fig. 7, were obtained by using values of *b*, 1 × 10^{-70} and 2 × 10^{-70}, respectively. In a crystal the ionic charges are largely balanced, and according to Polanyi the value of *e* is seldom greater than 1/5 *e* for univalent crystals. Values of $z = 0.3$ for potassium and 0.55 for oxygen, have been used in Eq. 7, and the results combined with the van der Waals interaction (Eq. 4), to obtain curve 5, Fig. 6 and curve 3, Fig. 7. While the values chosen may be somewhat high, they are in the direction to compensate for any other small attractive terms that may enter. The minima occur at 0.010 and 0.015 electron volts, or 120 and 350 cals./mole. It is interesting to note that calculations involving widely different repulsive potentials (using $b = 0.5 \times 10^{-70}$ and 1.0×10^{-70}), with consequent increase in the energy of interaction, do not cause any great change in the position of the minimum at R_0 for the system He–O. The range of values of R_0 for different positions of the minimum is given by the dotted curve *PQ*, Fig. 6. There is even less difference in the interatomic distance at which the repulsive potential rises abruptly. These considerations point to a fairly low error in the interatomic distances thus obtained. The positions of the minimum, R_0, for the systems He–O and He–K are 2.6 Å and 2.5 Å respectively, and since the radius is 1.32 Å for both the oxygen ion and the potassium ion, the effective radii of helium at equilibrium distances from these ions are 1.3 Å and 1.2 Å, respectively.

For the problems to be discussed later in connection with the retention or diffusion of helium in rocks and glasses, the effective radius that determines the diffusibility is not R_0, but rather the distance at which the repulsive part of the potential energy curve rises abruptly, that is, where a considerable increase in energy is required for a small change in the interatomic distance. This latter distance gives an effective radius for helium of 0.95 Å, which indicates that an energy of 0.5 e. v. or 13,000 calories is required to bring a helium atom and an oxygen atom within a distance of 2.0 Å. The probability of an atom's having this thermal energy at 300° K. is 1 in 10^9.

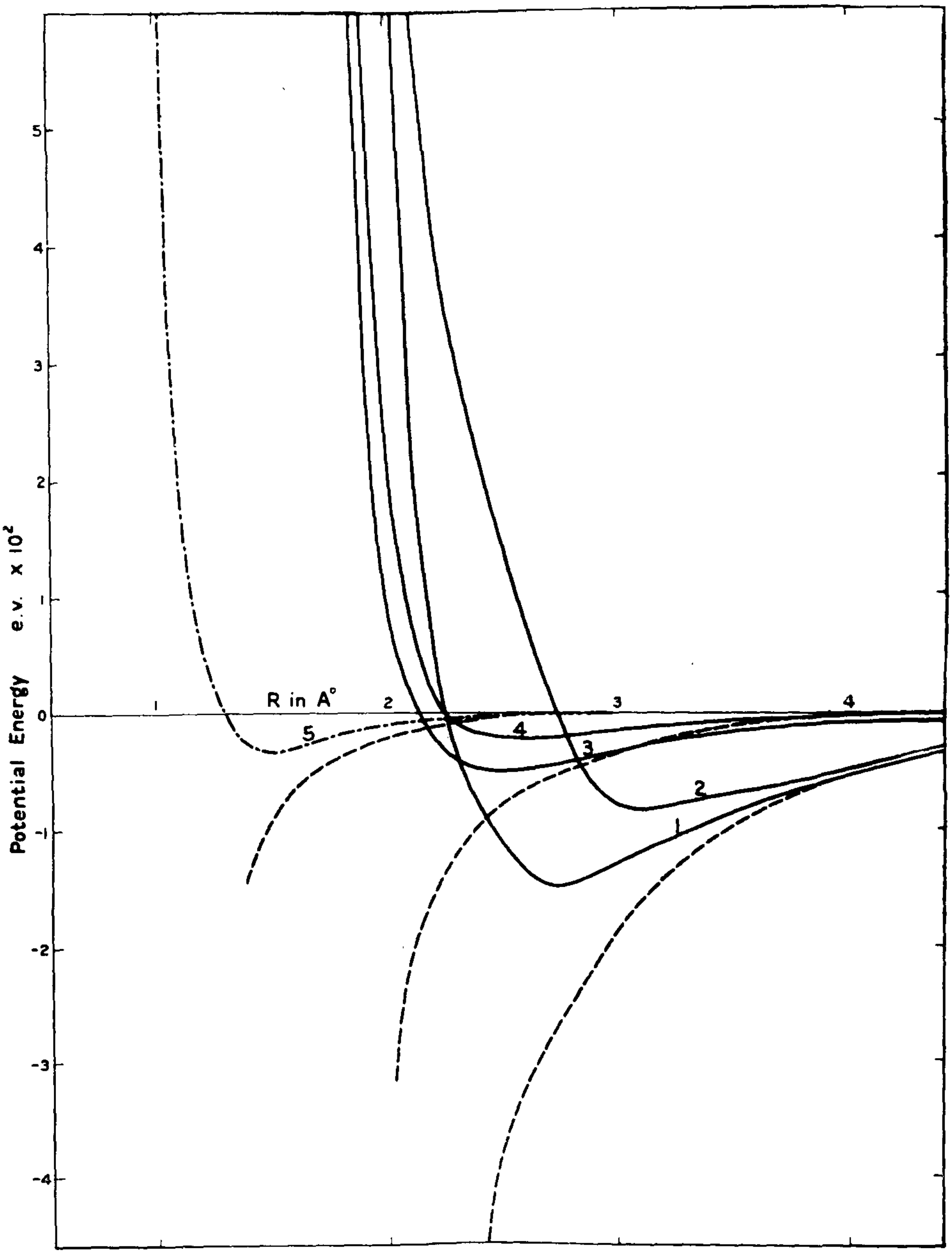


Figure 7. Potential energy curve for He and K, curve 4. Curves 1 and 2 are for the polarization potential energy between helium and a single charged ion with $b = 1$ and 2.0×10^{-70} respectively. Curve 3 represents the combined effect of the van der Waals and ionic polarization forces for He-K. Curve 5 is an approximate curve for He-Si. The change of the attractive potential with interatomic distance, R, is shown by the lower dotted curves.

Comparison of Determinations of the Dimensions of the Helium Atom

It will be interesting to compare the values for the radius of the helium atom calculated in other ways and those determined experimentally with the results found above. Such data are summarized in Table II.

Another method of obtaining the dimensions of the helium atom is to find the radius from the point where the radius curve for ions with the

TABLE II

Dimensions of the Helium Atom in Different Environments

System	Method Employed	Reference*	Radius in Ångstrom units	
			For equilibrium distance	At point where repulsion increases abruptly
He–He	Viscosity	Jeans, and Loeb		1.08
	Heat Conduction	Jeans, and Loeb		1.14
	Mean Free Path	Jeans, and Loeb		1.11
	Van der Waals "b"	Jeans, and Loeb		1.15–1.32
	Wohl's "b"	Jeans, and Loeb		1.07
	Gas Isotherms	Loeb		1.12–1.39
	Slow moving electrons	Loeb	1.41	
	Molecular refraction	Loeb		0.74
	Early calculations	I. C. T.		0.6–0.81
	Wave function method, dipole interactions	Slater	1.5	
	Ditto, perturbation method	Slater and Kirkwood	1.45	
	Perturbation method with quadruple and dipole interaction	Margenau	1.43	
	Repulsion calculation	Rosen	1.45	
	Vibrational method of calculating perturbation energy	Page	1.45	
	At strong repulsion	From V–R curves		1.1
	Quantum statistics	Gropper	1.5	
	Joule-Thompson Coefficients	Hirschfelder	1.4	
	Solid He	Pauling and Wilson	1.75	
He–He$^+$	Calculation for helium molecule ion	Pauling	<1.0	
He–K	See text	This paper	1.2	
He–O	See text	This paper	1.3	
He–O	At strong repulsion	This paper		0.95

* Jeans, Dynamical Theory of Gases, Cambridge University Press; Loeb, Kinetic Theory of Gases, McGraw Hill, 1934; Slater, Phys. Rev. *32*, 349–360 (1928); Slater and Kirkwood, Phys. Rev. *37*, 682–697 (1931); Margenau, Phys. Rev. *38*, 747 (1931); Rosen, Phys. Rev. *38*, 255 (1931); Page, Phys. Rev. *53*, 426 (1938); Gropper, Phys. Rev. *50*, 963 (1936); Pauling, J. Chem. Phys. *1*, 56 (1933); Pauling and Wilson, Introduction to Quantum Mechanics, McGraw Hill, 1935: Hirschfelder, Ewell and Roebusch, J. Chem. Phys. *6*, 205 (1938).

helium shell crosses the point of zero ionic charge. The result should prove useful in our present problem because the effective ionic sizes are fairly constant in common minerals, and fall along a smooth curve (Fig. 8). The ionic sizes are those most commonly found in normal compounds;[5] the effective size of helium and other inert gas atoms which would be found in similar environments may be obtained simply by interpolation. The size of the helium atom found in this way from crystal ionic sizes may be used as a check on our calculations. The values obtained from Fig. 8 for the inert gases are He = 1.17, Ne = 1.26, A = 1.68 Å, all in good agreement with the calculated and the experimental values.

The values given in the last column of table III are lower than the calculated values for the effective radii in the helium polarization molecule (Figs. 3, 5), since the fast moving helium atoms in the gas will approach each other more closely upon collision than the normal equilibrium distance. The radius to be compared should be that at which the repulsive part of the potential energy curve rises abruptly. The value 1.1 Å obtained in this way is in good agreement with the experimental values. In the curves between helium, and oxygen (Fig. 6) and potassium (Fig. 7), the interatomic distances at the point where repulsion increases rapidly are 2.2 and 1.9 Å. Since most rock minerals are essentially close packed oxygen ions, the effective radius of helium is 0.95 Å. A comparison with the other values for the radius of helium suggests that any corrections in this value would be positive. The important thing to note is that the helium atom is large compared to many common rock ions (Figs. 4, 8). There are

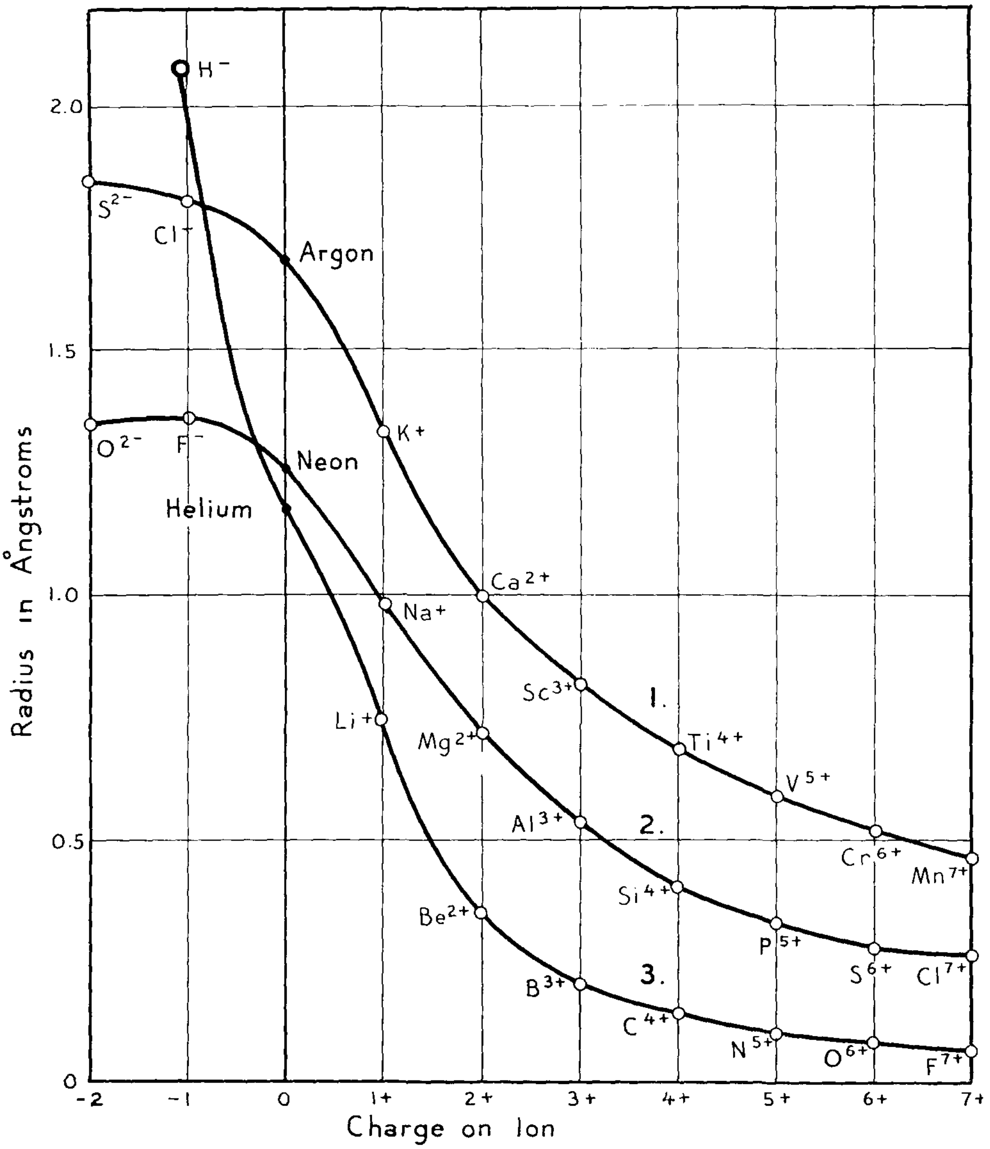
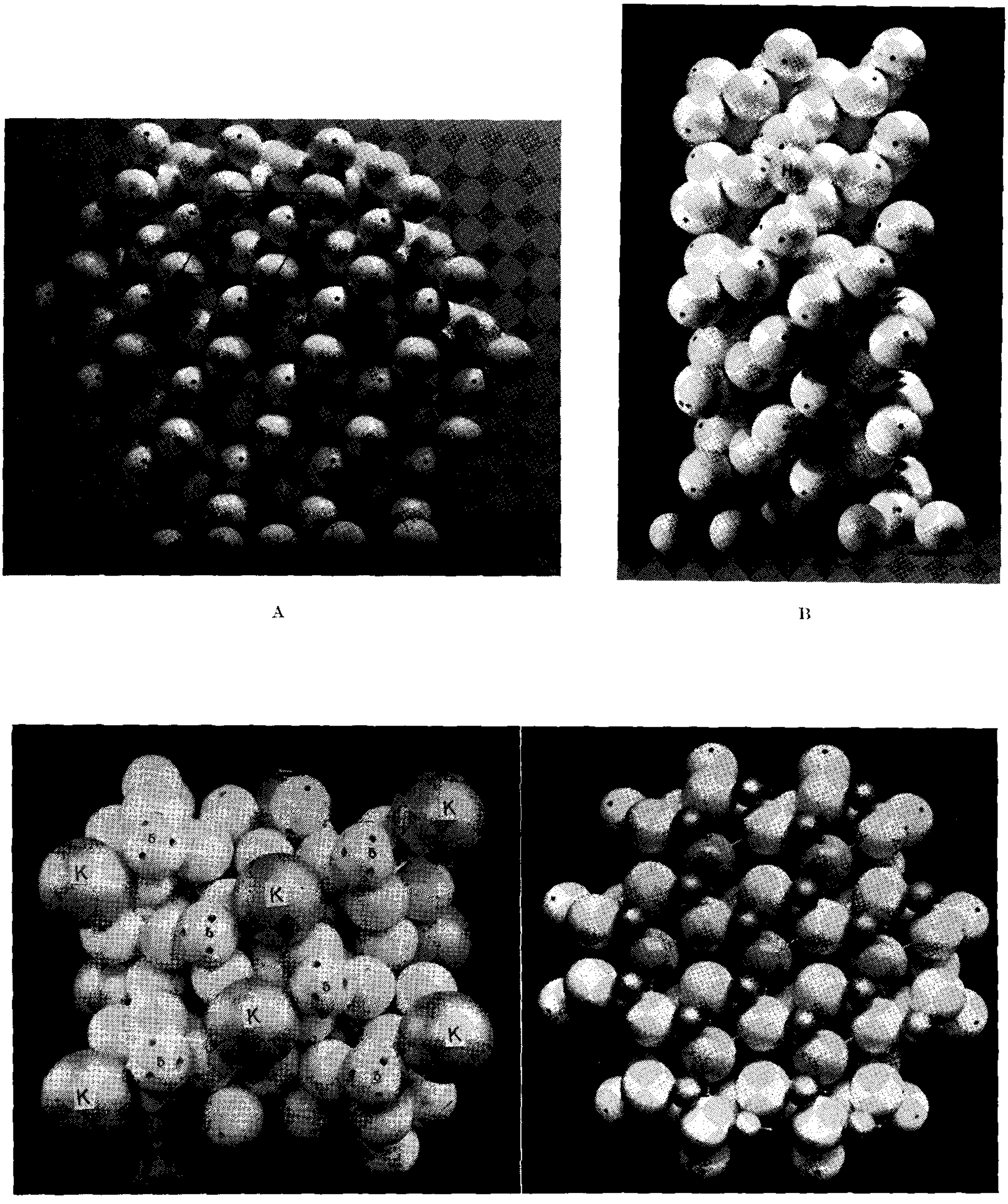


FIGURE 8. Crystal radii (open circles) for a number of ions

1) Argon shell, 2) 2) 6) 2) 6
2) Neon shell, 2) 2) 6
3) Helium shell, 2) 2

Useful in obtaining by interpolation the size of the inert gas atoms (solid circles) in the environment of the crystal.

not the variations with environment in the effective radii of helium, neon, and argon that exist between other atoms, because of the fact that the outer electron shells of the inert gas atoms are complete, and there is no tendency to chemical reaction. The variations in the depth of the potential energy troughs are small; the repulsive forces predominate at greater distances, are similar in nature for all environments, and result in a fairly constant atomic size. Since the interatomic spacings in the ideal crystal structures of minerals are constant known quantities, models can be constructed with the atoms as spheres of the proportionate sizes found from X-ray measurements. The size of the helium atom model can then be compared with the interatomic distances



A B

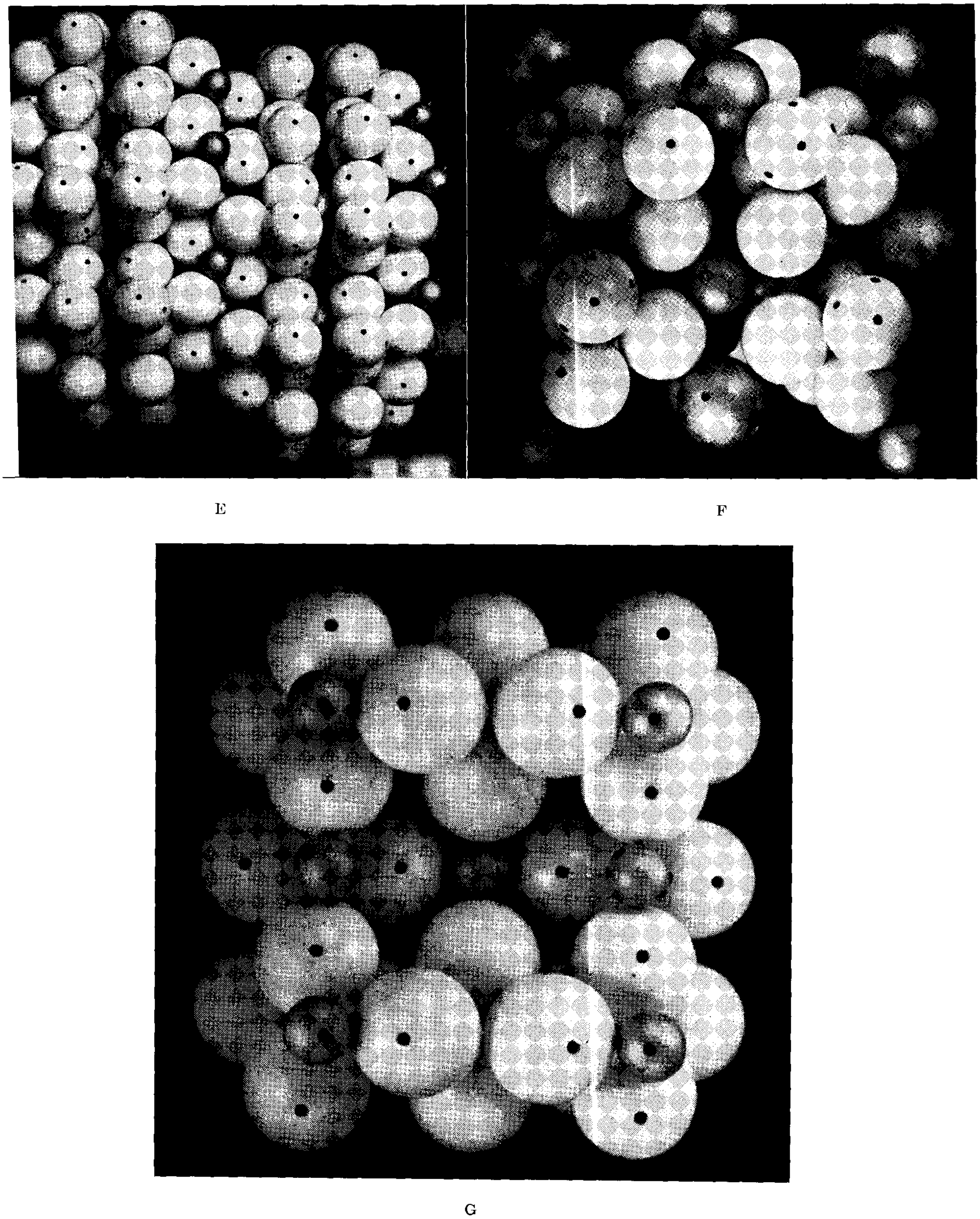
C D

FIGURE 9. Photographs of models of several silicate structures constructed by M. J. Buerger and co-workers.

(a), (b), Alpha quartz. (a) is viewed parallel to the C-axis showing the largest channels in the structure. The visible atoms are oxygen of radius 1.3 Å. The sizes of the spheres below the model are from left to right: 0.87 Å, 0.94 Å, 1.0 Å (He), 1.06 Å, and 1.12 Å. R is the interatomic distance between oxygen and an atom in a channel.

(c), Feldspar (sanidine) model viewed parallel to the b-axis.

(d), Planar sheet of muscovite mica.



(e), Complete muscovite mica model viewed almost along the *b*-axis, to show the channels in the plane of cleavage through the *K* atoms.

(f), (001) view of the diopside structure, *a*-axis horizontal, *b*-axis vertical.

(g), Top view of the zircon structure viewed parallel to the *c*-axis.

In all of these models the oxygen atoms predominate, and are 1.3 Å in radius. The relative size of helium atoms may be obtained from this dimension, or roughly by comparison with (*a*).

and spaces between the atoms in the crystal. This is done in Fig. 9 for several common rock minerals: quartz, feldspar, muscovite, diopside and zircon.

Summary

An examination of the interatomic forces and interatomic distances between helium and other atoms has been made. It has been found that the dimensions of the helium atom are relatively constant compared to those of atoms other than the inert gases. It is important to note that the helium atom is large compared to the spacings within most crystal structures. The results are summarized in Table III.

TABLE III

Summary of Data on the Size of the Helium Atom

Method of calculation	Radius at Equilibrium distance Å	Radius Å	Effective radius at the point at which the effect of repulsion increases abruptly Å
Experimental, He–He			1.18
Calculated, He–He	1.45		1.10
Calculated, He–O and He–K	1.25		0.95
Interpolation from radius-ion charge plot for He shell (Fig. 8)		1.17	
Size of oxygen ion		1.3	
Size of silicon ion		0.4	
Size of maximum spacing in quartz (Fig. 9)		0.3	
Size of large spacings in glass		1.9	

III. Diffusion

The Diffusion of Helium through Glasses

Because of the size of the helium atom, relatively large holes are required before it can diffuse through a close-packed solid. Some insight into the mechanism of the diffusion of helium can be obtained by finding what the repulsive forces predict as to the minimum width of channels for diffusion, and by a study of the diffusion through fused silica and various glasses.

In the first place, experimental evidence indicates that only the lighter gases can diffuse through glasses, which suggests that the pores are of molecular dimensions. The amount of diffusion is directly proportional to pressure and inversely proportional to thickness, so that equilibrium appears to be reached rapidly between the pressure and vacuum sides of the specimen. The results obtained by different investigators[13] for the relation of diffusion to pressure have been compiled, and illustrated in Fig. 10. In all cases the permeability* is proportional to pressure. (Urry considered that his results indicated a log P-log U relation, but the deviations of the P–U plot are of the order of the experimental error of measurement.) The linear relation between thickness and pressure can be explained by the existence of innumerable small and continuous channels throughout the glass.

Forces Within Channels

Since the pores are of atomic dimensions, the diffusing atoms must be under the influence of the repulsive and attractive forces of the atoms along the walls. Fig. 11 shows the resultant effect of these forces along uniform channels of various widths. Fig. 11a shows a channel 12 Å wide in which free diffusion of helium can occur. Only the low activation energy necessary to overcome a small amount of attraction would be required to keep the helium moving along the channel Fig. 11b illustrates the greater influence of attraction at the centre of the 7 Å channel. Diffusion in this case also would be relatively free. In a uniform glass, it is unlikely that there are any pores greater than 6 or 7 Å in diameter. Th situation in a typical channel in fused silica o glass 4.4 Å in width, is probably better de picted by Fig. 11c. Here the helium atom mus possess a considerable activation energy in orde to overcome the repulsive force of the wall atoms In all of these cases the border of the channel ha been taken as the line passing through the centre of surface atoms.

It should be noted that in Fig. 11b, for exampl the attractive potential illustrated is the max mum for the system He–O, and this would be th case only above oxygen ions. At other point on the surface of the channel, the depth of th

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[13] Van Voorhis, Phys. *A32*, 557 (1924); T'Sai an Hogness, J. Phys. Chem. *36*, 2595 (1932); Barrer, Chem. Soc. *378* (1934); Braaten and Clark, J. A Chem. Soc. *57*, 2715 (1935); Braaten, Private co munication; Urry, J. Am. Chem. Soc. *54*, 3887 (1932)

Note: The units for Figs. 5 and 7 in the paper Urry are incorrect. In Fig. 5, the values for log reading from $\bar{9}.0$ to $\overline{11}.5$ should be changed to − 8.0 − 10.5, and in Fig. 7 those now reading $\bar{9}.0$ to 1 should read − 8.0 to − 11.0. The intermediate poi of the grid are correct ($\bar{9}.5$, $\overline{10}.5$, and so on).

* cc. of He passing through one square cm. of gla one mm. in thickness, per hour.

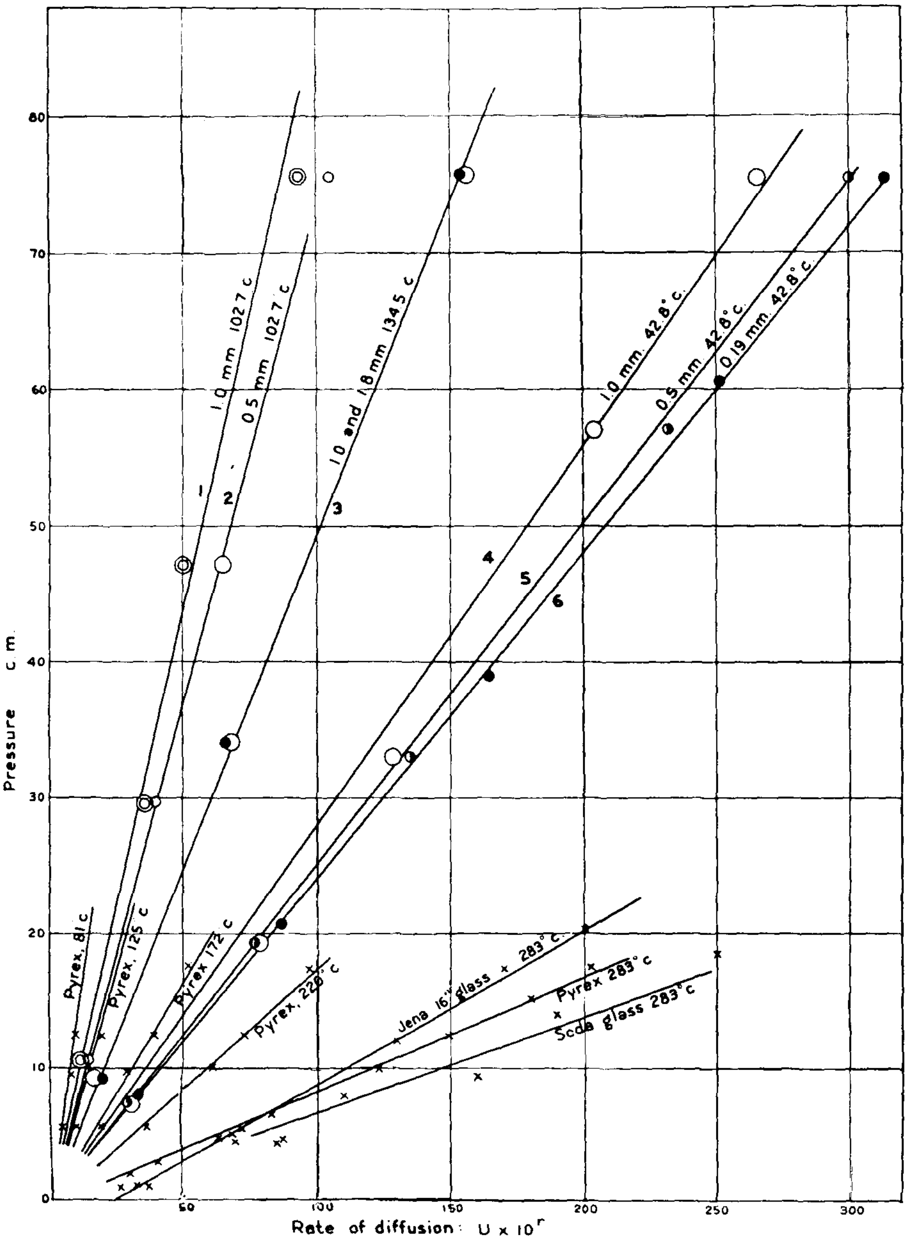

FIGURE 10. The rate of diffusion of helium through silica and various glasses, showing the linear effect of pressure. Curves 1 to 6 from the data of Braaten and Clark, the others (crosses), from Urry's data. For curves 1 and 2, $r = 10$; 3 to 6, $r = 9$; for pyrex glass, $r = 9$; for lead glass, 8; for soda glass and for Jena glass, 7.

minimum would be less. This is brought out more clearly by a potential energy contour diagram of a crystal surface, similar to that described by Lennard-Jones for somewhat simpler crystals.[8b] Fig. 12a shows the approximate distribution of energy for a helium atom on an (010) face of orthoclase feldspar. The crosses and dots represent the centres of potassium ions and oxygen ions on the surface, respectively. Any atom migrating over such a surface or in a channel will tend to follow the potential energy contours, but according to the wave mechanics, there is a certain probability that an atom can also cross potential energy barriers. Such a periodic distribution of energy occurs normal to the crystal also, and to complete the three-dimensional picture, the distribution of energy levels for helium above a crystal surface is shown in Fig. 12b. The circles represent a helium atom and a surface oxygen atom in contact at one of the positions of equilibrium. The three figures may be more readily correlated by comparing the locations of corresponding points A, B, and C, in Figs. 11a, 12a and 12b.

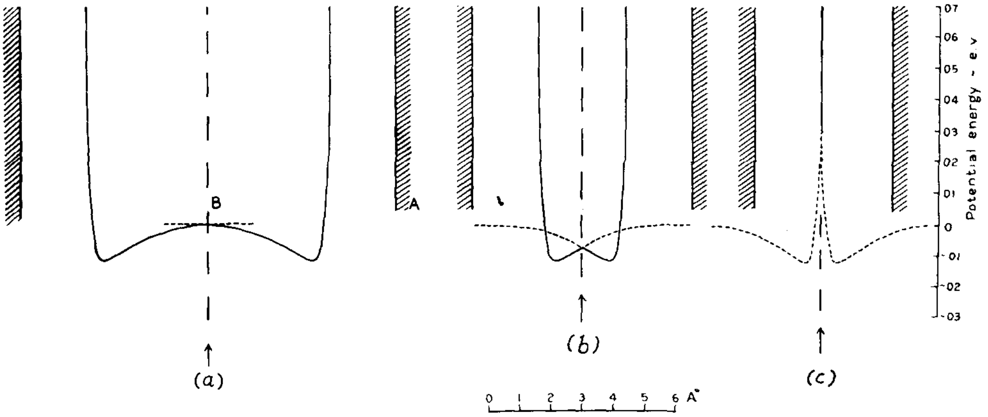

FIGURE 11. Potential energy curves for helium in channels in solids. a) Channel width of 12 Å, through which a helium atom may pass freely as indicated by the dotted line.

b) Channel width 7 Å. Helium is attracted by the walls, and a small activation energy to overcome the force of attraction is required for diffusion.

c) Channel width 4 Å. Forces of repulsion enter so that the activation energy required for movement of helium through the channel is high, and increases very rapidly as the width of the channel decreases.

Activation Energy of Diffusion

The above considerations indicate that, unless the pores in glasses are relatively large, a considerable activation energy will be required for the diffusion of gases. This conclusion is verified by experiment. Since the diffusion is known to be related linearly to pressure and to thickness, the energy requirements can be studied easily by measuring the rate of diffusion as a function of temperature. The results of several investigations are plotted in Fig. 13, where it will be observed that the logarithm of the rate of diffusion varies as $\frac{1}{T}$. The rate, U, may then be expressed by:

$$U = BPe^{-E/kT} \ldots\ldots\ldots\ldots\ldots (8)$$

a form derived by Lennard-Jones[8b] and Alty[14] where B is a constant, k is the Boltzmann constant, and E the energy of activation required before a molecule can diffuse through the solid. Lennard-Jones[8b] and Urry[13] considered that the mechanism of diffusion involved surface adsorption followed by subsequent diffusion, but the theory that the atoms enter the solid directly from the gas phase seems more plausible for the cases of the inert gases in view of the low adsorption energies (Figs. 5, 6, 7).

The activation energies calculated from the slopes of the (log U) *vs.* $\frac{1}{T}$ plots are given in Table IV. The activation energy is made up of a number of terms, and has been treated by Alty[14] as:

$$e^{\frac{-(W_0 + E_0)}{RT}}$$

where W_0 is the energy necessary for the atom to overcome a potential barrier at the surface and E_0 is the energy necessary for the atom t move along the channel. Lennard-Jones considers that a term W_A is present when the diffusion is preceded by adsorption on the surface Another term should be included to take accoun of the migration with temperature of alkali an metal ions in glasses. Alty and others hav pictured the channels as occurring between numerous adjacent small crystals, but this is not likely structure for glass and is not a necessar postulate. The theory of the vitreous stat

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[14] Alty, Phil. Mag. *15*, 1035 (1933).

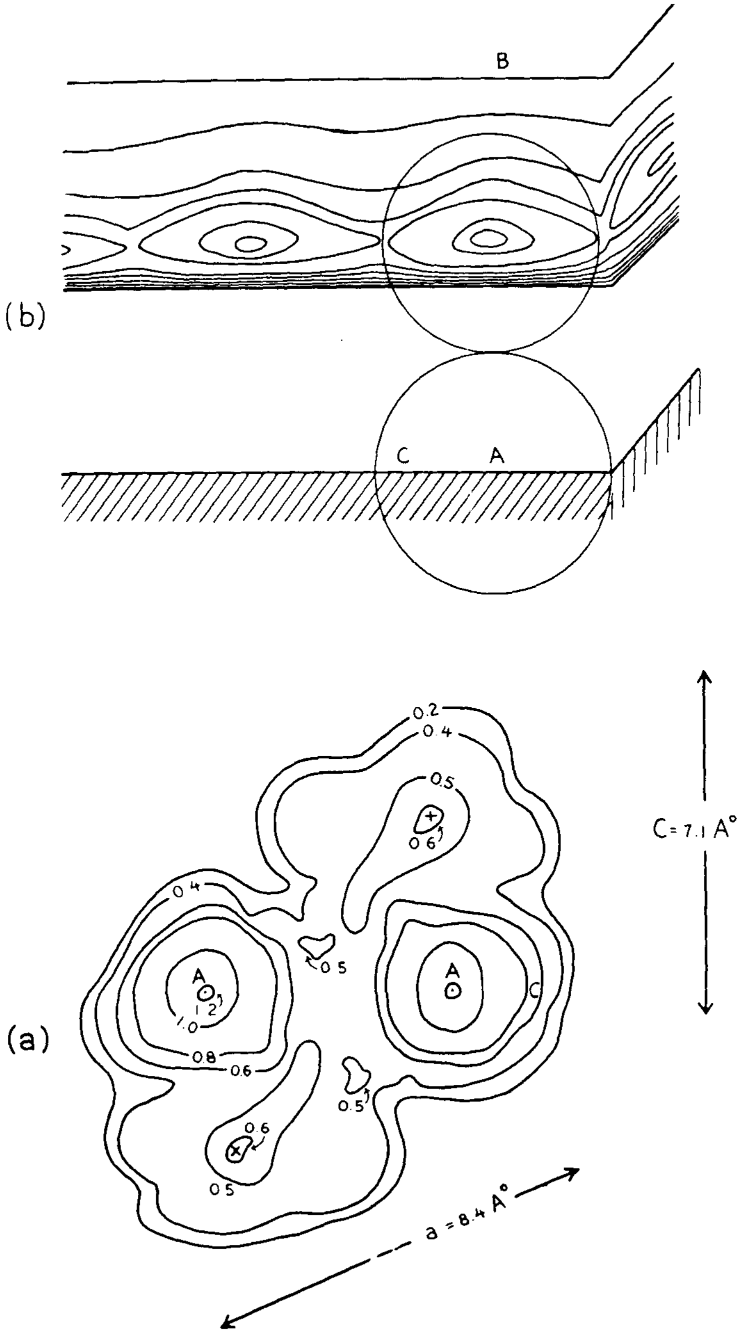

FIGURE 12. a) Approximate energy contours over a surface of a crystal. The letters *A*, *B*, *C* are to be compared with those in Figure 12b and Figure 11. The surface is the (010) face of orthoclase feldspar. The crosses mark the attraction loci at the centre of potassium ions, the dots (*A*) the attraction at surface oxygens. Helium will form transitory adsorption compounds at these points, and may be removed by direct evaporation through thermal energy, or by moving along and sometimes across potential energy contours or barriers to adjoining equilibrium positions on the surface.

b) represents the energy distribution normal to the surface. The upper circle represents a helium atom attracted over an oxygen ion *A*; the attraction is a maximum at points corresponding to the centre of the upper circle. Repulsion increases rapidly as the atom moves from one of these points towards the surface *AC*.

TABLE IV

ACTIVATION ENERGIES FOR DIFFUSION THROUGH GLASSES

Substance	Gas	Temperature Range, °C.	Activation Energy cals.	Reference
Vitreous Silica	He	−78–127	4,700	Braaten and Clark
Vitreous Silica	He	127–540	5,500	Braaten and Clark
Vitreous Silica	He	180–977	4,700	T'sai and Hogness
Vitreous Silica	He	200–900	5,700	Barrer
Pyrex Glass	He	125–285	ca. 5,500	Urry
Pyrex Glass	He	200–500	7,600	Van Voorhis
702P Pyrex	He	200–500	7,900	Van Voorhis
Vitreous Silica	Ne	517–977	9,650	T'sai and Hogness
Vitreous Silica	H_2		10,000	Barrer
Vitreous Silica	Air	420–920	20,000	Barrer
Vitreous Silica	N_2	850–940	22,000, 30,000	Barrer
Vitreous Silica	N_2		26,000	Johnson and Burt
Vitreous Silica	O_2		31,000	Barrer
Vitreous Silica	A	940–1000	48,000 (?)	Barrer

proposed by Zachariasen[15] is the most consistent with X-ray data and other experimental facts. According to this theory, a crystal tetrahedral arrangement of four oxygen atoms around each silicon persists in silica glass and they are joined together as a continuous structure. However the arrangement in glasses lacks any of the regularity and periodicity of perfect crystals, and this means that various sized holes will be present in the structure, and the density less. This picture of a random network has been verified by Warren[16] in X-ray studies of several glasses. In a glass the cations are held in some of the holes, but are not in any definite proportion, because of the variable composition of glass. These cations are not bound very tightly, and some migration will *take place with rising temperature. Since the* attractive and repulsive energies are exponential functions, the extent of migration would be expected to vary exponentially with temperature: $e^{-E_c/kT}$. The activation energy of diffusion, E in Eq. 8, may then be considered to be composed of at least four terms, of which W_0, that necessary to overcome the repulsive potential of the walls, is the most important.

$$E = W_0 + W_A + E_0 + E_c \ldots\ldots (9)$$

The larger the sum of these terms, the less is the probability of diffusion.

The Number and Size of Holes in Glasses

Among glasses, the most numerous and largest continuous pores will be found in vitreous silica Added cations in other glasses will fill some of the holes, blocking some channels and increasing the repulsive energy in others. This will result in a slower rate of diffusion and an increased activation energy as found by experiment. Increasing *the size of the surface at the outlet or low pressure* side does not affect the diffusion noticeably For practical purposes, then, it may be assumed that the pores are distributed regularly norma to the surface. Not all gas atoms colliding wit the surface will diffuse through, since a certain activation energy is necessary, and the hole occupy only a small fraction of the surface.

*It is found that the number of effective colli*sions is only about one in a billion for helium o vitreous silica. The results of calculations of th fraction of activated molecules diffusing throug silica are shown in Table V. The table is sel explanatory.

The probability of an activated atom's collidin with the opening of a "channel" will be equal t the ratio of the area of the holes to the total are The total number going through 1 sq. cm. wi then be:

$$N = \frac{n\bar{u}}{4} \cdot e^{-E/RT} \cdot \frac{\text{area of holes}}{1} \cdot \kappa \ldots (1$$

where n is the number of atoms per cc. in the ga *and $\bar{u}$, the average velocity in cm. per sec.,* κ an orientation factor which takes into account t

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[15] Zachariasen, J. Am. Chem. Soc. *54*, 3841 (1932).

[16a] Warren, Z. Krist. *86*, 349 (1933); and papers in press.

[b] Warren and Loring, J. Am. Ceram. Soc. *18*, 269 (1935).

TABLE V

Number of Activated Atoms of Helium Colliding with Surface, and the Number Diffusing Through Vitreous Silica

Temperature °K.	Velocity of He atom $\bar{u} \times 10^{-5}$ cm. per sec.	No. colliding per sec. with 1 cm.² of surface $\times 10^{-24}$	$\frac{-E^*}{RT}$	No. of activated atoms colliding with surface per second $\frac{n\bar{u}}{4} e^{-E/RT}$	No. diffusing through per second, experimental	F = fraction of activated atoms going through
273	1.2	0.80	8.7	1.3×10^{20}	7×10^{10}	5×10^{-10}
393	1.5	1.11	6.1	2.5×10^{21}	1×10^{12}	4×10^{-10}
503	1.7	1.25	5.2	6.9×10^{21}	4×10^{13}	6×10^{-9}
683	2.0	1.45	4.0	2.7×10^{22}	2×10^{14}	7×10^{-9}
773	2.1	1.55	3.5	4.7×10^{22}	3×10^{14}	6×10^{-9}

* E = 4800 at T = 273° and 393°, 5200 at 503°, 5500 at 683° and 773° K. (see Fig. 13); R = 2 cals./mole./degree.

fact that some of the activated atoms colliding with a hole will not get through because of striking the surface at a sharp angle; it is probably less than 0.1. The results in the last column show that F is fairly constant, at least at higher temperatures, and is about 6×10^{-9}. The total area of the holes per sq. cm. of surface is then about 10^{-8} sq. cm. If we assume that the average radius of the holes larger than the helium atom is 1.3 Å, the total number is computed to be about 10^8 per sq. cm. The holes in glass are probably about 6 or 7 Å apart on the average, so that there are about 2×10^{14} per sq. cm. Apparently only one in a few million is large enough to permit diffusion of helium through a thickness greater than a tenth of a millimeter of vitreous silica, and it seems quite plausible that the diffusion would be reduced to zero in the twenty-two per cent decrease in volume in the regular ordered arrangement of crystalline quartz.

The other way to decrease the permeability is to increase the size of the diffusing atom. This has been done for several atoms. The decrease in permeability and the increase in activation energy in going from helium to neon to argon, are shown in Table VI.

The sizes of the various holes in the glass will be more or less statistically distributed, the largest number being close to the average spacing in the stable crystalline structure, about 0.3 Å across. The number of successively larger spaces falls off rapidly, and the rate of diffusion decreases similarly for larger ions. The way in which this variation can occur may be seen by referring to some simplified two-dimensional drawings to be found in the literature.[15, 16b, 17]

The number of molecules, N, with the necessary activation energy for diffusion is given by:

$$N = N_0 \cdot e^{-E/kT} \quad \ldots\ldots\ldots\ldots (11)$$

where N_0 is the total number of impinging molecules (about 10^{23}), and E is the activation energy.

Since T does not ordinarily exceed 1,200° K. in diffusion experiments on silica glasses, and N_0 is fixed for any temperature and pressure, the maxi-

TABLE VI

Some Deductions from Diffusion Data for Helium, Neon, and Argon through Silica Glass

Gas	Radius of atom in Ångstroms	Activation energy, cals.	Fraction of activated molecules diffusing through	Assumed average size of hole Å	Approximate no. of this size per sq. cm.
Helium	1.0	5,500	6×10^{-9}	1.3	10^8
Neon	1.3	9,700	4×10^{-11}	1.5	10^5
Argon	1.7	48,000 (?)	ca. 10^{-14}*	1.8	≥ 0

* T'sai and Hogness found no argon diffusing through silica; Barrer found a trace, possibly through imperfections.

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[17] Ewell, J. App. Phys. *9*, 262 (1938).

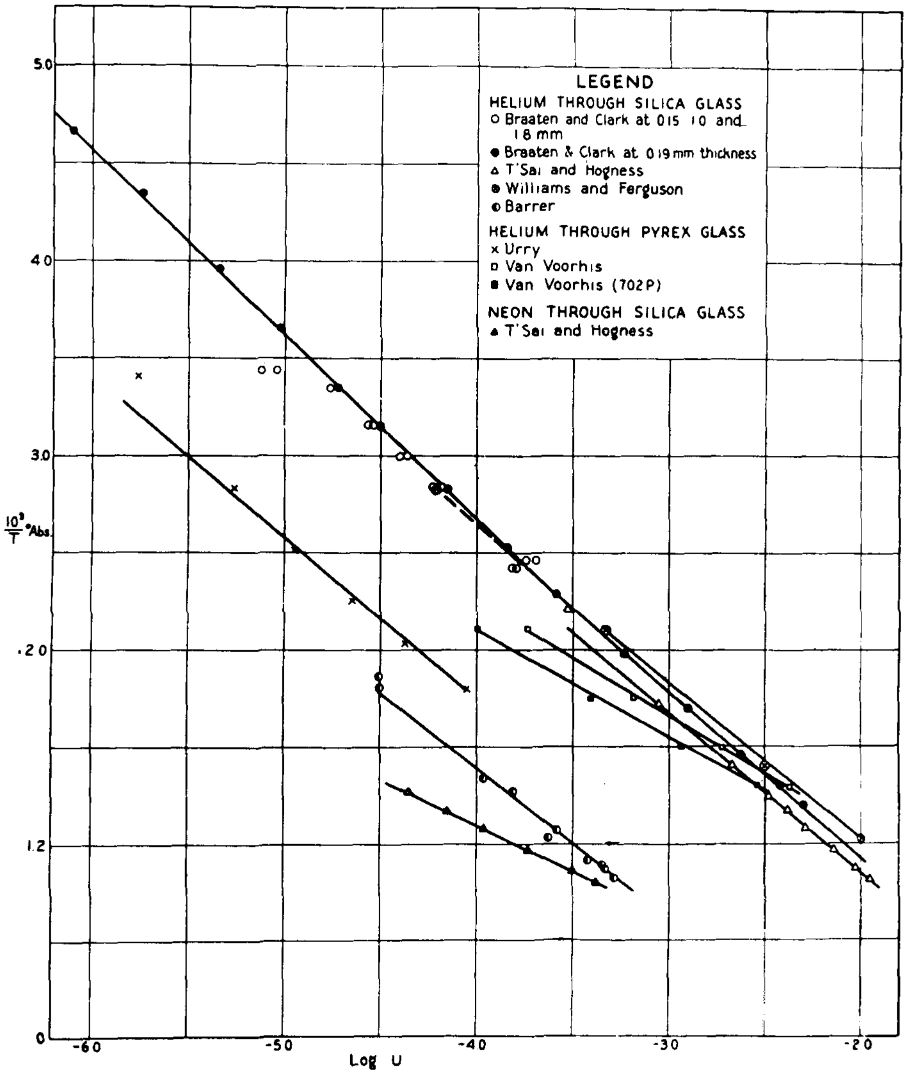

FIGURE 13. The effect of temperature on the diffusion of helium and neon through vitreous silica and pyrex glass. U = rate of diffusion in ccs. per hour though 1 sq. cm. of surface and a thickness of 1 mm.

mum activation energy for diffusion is obtained from Eq. 11:

$$\frac{N}{N_0} = 10^{-23} = e^{-E/2400}$$

from which E = 127,000 cals. With a minimum range of detectability of about 10^4 atoms a second, and a probability factor of about 10^{-10}, it would be difficult to detect the diffusion of atoms requiring activation energies greater than 50,000 cals. The activation energies of successively larger inert gas atoms, He (1.0 Å), Ne (1.2 Å), and A (1.7 Å), are 5,500, 9,600, and about 48,000 cals., respectively. These results combined with those of Table VI would indicate that the diffusion of atoms larger than argon could not be detected experimentally (under a pressure gradient of one atmosphere or less), and roughly that no particles greater then 2.0 Å in radius could diffuse through silica glass. For gases other than the inert gases the maximum size may be even greater than this, due to the entrance of greater attractive forces. Two gases that have not been investigated, CO and NO, both having a radius of 1.15 Å, might be expected to diffuse through silica. Argon has a size nearly that of the limiting diameter, so should diffuse with difficulty; T'sai and Hogness could find no trace of argon on the low pressure side, while Barrer found the diffusion to be very slow (even at 1000° C.), unless the surface was treated with hydrofluoric acid. This treatment invalidates the diffusion results, because the acid molecules are small enough to diffuse through the silica and readily react chemically, so that the effect may be more than a superficial one.

Differences Between Crystals and Glasses

While the above experiments have revealed that several silicate glasses are permeable to helium and to some other light gases, the results have shown that the diffusion is relatively slow, and that only a few of those atoms with energy greater than a certain critical energy can pass through. The change of the permeability and activation energy with the size of diffusing atoms indicates that the accessible pores are only of atomic dimensions, and that the number of these is exceedingly small compared to the total number of interatomic spacings. There is a tendency for the larger pores to be filled up by the rearrangement of the vitreous network in the "aging" process. In glasses that had partially crystallized with age, Barrer[13] observed that the rate of diffusion had decreased. If this process of reorientation were to continue until the close-packed atomic arrangement of crystals were formed, the larger metastable holes would disappear, and the permeability to helium would approach zero. The results of X-ray analyses of minerals provide quantitative data regarding the dimensions of the component atoms and of the "pores" between them. In common rock minerals, as shown later, the total "free space" is relatively large, but the actual size of any one opening between atoms is small compared to the size of the helium atom. This is illustrated in Fig. 9, where a helium atom is compared to quartz and several other crystal models. If the planar model of a glass structure[15] is compared with these crystal structures, it is observed that while the chain-like silicon oxide networks are present in both, they differ in that the glass lacks the periodicity and regularity of the crystalline structure, and these deviations from the stable close-packed arrangement bring about larger spaces between atoms.

The Crossing of Potential Energy Barriers

The preceding discussions of the potential energy of atomic interactions of helium and crystals have shown that helium atoms in rocks will be under the influence of either large repulsive forces or small attractive forces. Most often the helium atoms will be in some position of relatively low potential energy, similar to points "o" or "x", Fig. 12a, and will be surrounded by potential energy barriers arising from repulsion. These barriers may be low in channels or interstices greater than 4 Å in width, as illustrated in Fig. 11, and the change in potential energy along the course of the channel periodic, similar to the lower half of Fig. 14, but with much lower potential energy hills, so that thermal energy is sufficient to cause frequent crossing to adjacent valleys.

Most of the helium atoms in crystals would be expected to be in a more restricted environment than in such channels as occur in glasses or in the interstices in rocks. The probability of crossing to another equilibrium position would be much less because of the high activation energy required to squeeze between the small spaces (Fig. 9), where the repulsive forces are high. The problem is to find both the probability of such an occurrence, and the rate, so as to be able to evaluate its importance geologically where the factor of time is important. The situation is depicted diagrammatically in the upper part of Fig. 14. The helium atom is pictured as oscillating over small amplitudes in a position of equilibrium, and having on the average a kinetic energy $E_1 = 3/2\,kT$, due to thermal agitation. Before it can cross the barrier, according to classical theory, it must acquire the activation energy E or more. But the new quantum mechanics predicts a certain probability of penetration of potential energy barriers when the particle has an energy less than that corresponding to the peak, and before proceeding further we must determine whether this effect is large enough to be significant. The probability of such "tunneling" (Fig. 14) can be calculated, its magnitude depending upon the height of the barrier, and the distance across. The height of the barrier in our case will be governed by the spacings in the crystal network. From the interatomic distance, R, the corresponding potential energy can be obtained (Figs. 6 and 7). In common rock minerals (Fig. 9) the average size of the hole is less than 0.5 Å ($R = 1.8$), so that the activation energy would be about 10^5 cals. The spacings in crystals indicate that the minima would be separated by about 5 Å. With these values several calculations of the transmission coefficient[18] were made, which gave

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[18] Kemble, Fundamental Principles of Quantum Mechanics, p. 111, McGraw-Hill, 1937.

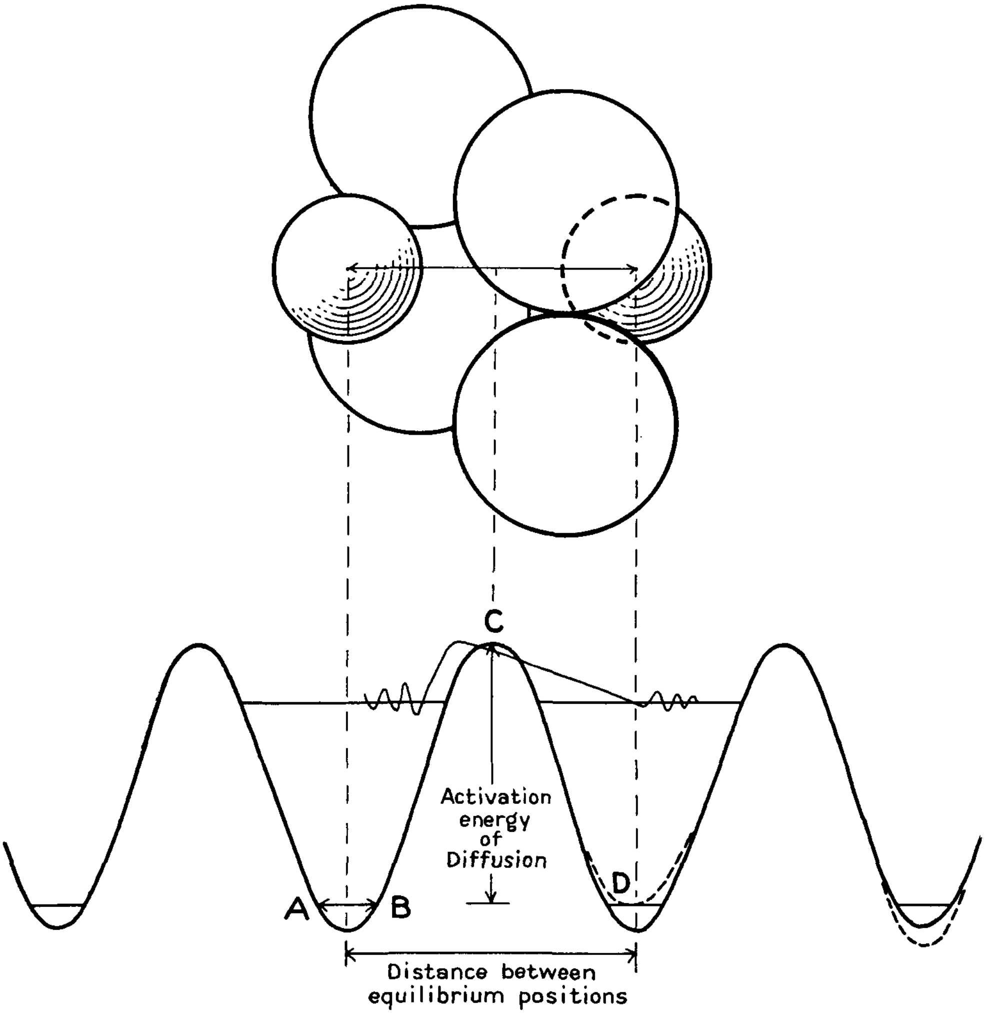
C
Activation energy of Diffusion
A
B
D
Distance between equilibrium positions

FIGURE 14. Diagrammatic representation of the potential energy profile of helium in a crystal. The minimum potential is at the equilibrium positions in the structural "holes" *A–B* and *D*. To pass from one to another, the atom must cross a potential barrier of height *C*. The effect of a concentration gradient in direction *B* to *D* would be represented by the dotted curves; in this case, the chance of crossing in the *BD* direction is greater than that of the atom's returning.

negligibly small values even when a time factor of 10^{20} seconds or more was taken into consideration. The possibility of penetration may therefore be neglected. This has been done by Eyring for similar cases in his theories of liquid structure and reaction rates.[19]

Method of Obtaining Rate of Diffusion in Crystals

The probability that the thermal energy of an atom will reach the requisite activation energy, E, is given by $e^{-E/kT}$. The problem of finding the rate, or the number of times the atom may cross a barrier per unit of time, is a little more difficult. In order to get a maximum estimate of this rate, let us consider a single helium atom in one of the equilibrium positions in a free space between crystal ions, A in Fig. 14. This will be oscillating between A and B with a frequency of the order of 10^{13} sec. $^{-1}$. This means that the atom reaches B, 10^{13} times per second, with a momentum in the direction AB. The problem may be treated, then, as if 10^{13} helium atoms were travelling per second towards the potential energy hill BC. The number of these, k, with sufficient energy to reach C and cross to the next equilibrium position D is given in the classical picture as:

$$k = 10^{13} \cdot e^{-E/kT} \qquad (12)$$

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[19] Eyring, Chem. Rev. *17*, 65 (1935). Eyring, J. Chem. Phys. *4*, 283 (1936).

which represents a rate in number of atoms crossing per second.

In the rate theory of flow,[20] diffusion and viscosity are treated as unimolecular rate processes in which the elementary process is the passing of a molecule from one equilibrium position to another, over a potential barrier. The motion is assumed to take place by an individual atom's occasionally acquiring the activation energy necessary to slip over the potential barriers which arise from the atom's squeezing between its neighbors to the next equilibrium position. The general theory involves the changes:

$$\overset{(1)}{\text{Initial state}} \rightleftarrows \overset{(2)}{\text{transitory state at barriers}} \rightleftarrows \overset{(3)}{\text{final state.}}$$

The rate constant is given by the equilibrium constant between (1) and (2), multiplied by the velocity at which the "complex" or the atom in the activated state crosses the barrier. The general equation is:

$$k_1 = K \frac{kT}{h} \frac{F_a^*}{F_n} e^{-E/kT} \quad \ldots\ldots.(13)$$

where k_1 is the rate constant

h is Planck's constant, 6.55×10^{-27} erg. sec.

F_a^* = partition function of activated complex, omitting one degree of translational freedom

F_n = partition function of the normal state.

The value of the coefficient of the exponential term for helium gas, where

$$\frac{F_a^*}{F_n} = \frac{h}{(2\,mkT)^{1/2} V_g^{1/3}} \quad \ldots\ldots.(14)$$

and m is the mass, V_g the free volume per atom, is 10^{-2}. It will be observed that Eq. 13 reduces to the same form[21] as Eq. 12,

$$k = Ae^{-E/kT} \quad \ldots\ldots\ldots\ldots(15)$$

the general equation for unimolecular reactions. The value of A found above is 10^{11}; those found experimentally for unimolecular reactions vary from 10^9 to 10^{15}, but more often within the range 10^{11} to 10^{13}. Rodebush gives A, in general, as $\frac{kT}{h}$, which is about 10^{13}. The rate constant, k, may be considered as the fraction crossing the barrier per unit of time. Since all of these treatments give the same general result, we shall use Eq. 15 with the value of $A = 10^{13}$ as in Eq. 12, in order to obtain a maximum rate. The greatest number of times a helium atom will cross a potential energy barrier in a half billion years (10^{16} secs.) will then be given by:

$$N = 10^{16} \times 10^{13}\, e^{-E/kT} \ldots\ldots\ldots(16)$$

To obtain the height of the potential energy barrier, E, we must find the sizes of the spaces between atoms, and the sizes of the "holes" and "channels" within some of the common crystal structures of interest. Knowing these, R and E can be found by following the methods illustrated in Figs. 6, 7 and 11. Since spacings of different sizes occur even in one mineral, and many are reproduced from crystal to crystal, we shall not consider each individually, but make calculations to cover the whole range from the smallest pore size to the large channels in which diffusion may occur readily.

In constructing the potential energy curves in Fig. 6 and 7, the repulsive potential was assumed to depend on an inverse ninth power of R, a satisfactory value for the purpose of finding an upper limit for diffusion, but it should be remarked that there is some arbitrariness in the choice of the dependence of V on R at short distances. Lennard-Jones[8b] has used also expressions involving R^{-11} to R^{-15} in calculations with the inert gases. Considering the stability and degree of close packing of the crystal structure, it seems probable that the ions would not be very deformable, and that the change of repulsion with distance, R, would be more closely represented by R^{-15} than by R^{-9}. Hirschfelder, Stevenson, and Eyring[20c] have used a general value of R^{-12}. At the interatomic distances within crystals, the attractive force may be neglected, and the potential energy obtained from $\frac{b}{R^n}$. It would be better to have a more accurate knowledge of this factor, but at least the upper and lower limits of the energy of interaction can be found. In Table VII, the approximate interaction energies between helium and an atom in a crystal at several interatomic distances (column 1) are calculated, using repul-

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[20a] Ewell and Eyring, J. Chem. Phys. *5*, 726 (1937).

[b] Eyring and Hirschfelder, J. Phys. Chem. *41*, 249 (1937).

[c] Hirschfelder, Stevenson, and Eyring, J. Chem. Phys. *5*, 896 (1937).

[d] Ewell, J. App. Phys. *9*, 252 (1938).

[21] Rodebush, J. Chem. Phys. *4*, 743 (1936).

sion terms $\frac{b}{R^9}$ (column 3) and $\frac{b}{R^{15}}$ (column 4). In crossing a barrier, the helium must squeeze through a space bounded by several atoms, so that the height of the barrier, E, will be several times the values for single interactions given in columns 3 and 4. The activation energy found experimentally for the diffusion of helium through glass may be used as a check on the calculations (column 5). To do this it is assumed that the experimental repulsion potential or activation energy of 5000 cals. is effective at an average value of $R = 2.3$ Å, and that it varies as R^{-12}. In the sixth column are given the values chosen for E. No assumptions about the positions of the boundaries of crystal atoms are necessary as the interatomic separations, R, can be obtained from experimentally determined X-ray spacings. The situation can be visualized by the use of models. In these R refers to the distance from the centre of a bounding oxygen atom to the centre of a spacing. The radius of a sphere which will just fit into the "hole" in the atomic packing model is given for convenience (column 2). The values in the seventh column in Table VII represent the probability of an atom attaining the thermal energy[22] necessary to cross a potential energy barrier, and move to the next point of lower potential energy within the crystal. It will be observed that at interatomic distances less than 2.1 Å this probability is small, and decreases very rapidly as the spacings become smaller in size. However, the enormous time factor of the geologic past must be taken into account, to find whether an appreciable number of helium atoms could diffuse through holes of smaller size.

The number of diffusing atoms is calculated by means of equation 16. Values of N for several different energy barriers are given in the third from the last column of Table VII. It will be observed that the critical interatomic distance is $R = 1.9$ Å, corresponding to a space 1.2 Å across, assuming as above that the bounding atoms are oxygen in their normal equilibrium positions. At this spacing the calculations indicate that an atom may cross about 10^4 barriers, but this does not necessarily mean its escape. The crystal is defined by the regularity and periodicity of its structure, and at least some of the helium atoms

TABLE VII

APPROXIMATE HEIGHTS OF POTENTIAL ENERGY BARRIERS FOR HELIUM AT VARIOUS DISTANCES IN RIGID CRYSTAL STRUCTURES ESSENTIALLY OF OXYGEN; AND AVERAGE DISTANCES OF DIFFUSION

R in Å	r of trapped atom	Energy of Interaction, cals.			Value of E used in calculations cals.	$e^{-E/RT}$	Number crossing in 10^{16} secs.	Average distance of diffusion in 10^{16} secs.	
		He–O		He–Vitreous silica					
		from $\frac{b}{R^9}$	from $\frac{b}{R^{15}}$	Extrapolation from experimental E_{act} of diffusion b/R^{12}		$T = 400°$ K		Using average $T = 400°$ K	Using average $T = 1000°$ K
1.4	0.1	2.1×10^5	4.2×10^6	1.6×10^6	3,000,000	10^{-1600}	10^{-1571}	10^{-793}	10^{-370}
1.5	0.2	1.2×10^5	1.6×10^6	7.4×10^5	1,000,000	10^{-550}	10^{-521}	10^{-268}	10^{-102}
1.6	0.3	6.5×10^4	5.7×10^5	3.3×10^5	400,000	10^{-200}	10^{-171}	10^{-93}	10^{-35}
1.7	0.4	3.7×10^4	2.3×10^5	1.5×10^5	200,000	10^{-100}	10^{-71}	10^{-53}	10^{-15}
1.8	0.5	2.3×10^4	1.0×10^5	8.2×10^4	100,000	10^{-50}	10^{-21}	10^{-18}	10^{-4}
1.9	0.6	1.5×10^4	4.4×10^4	5.7×10^4	45,000	10^{-25}	10^4	10^{-6}	10^2
2.0	0.7	8.7×10^3	2.1×10^4	2.2×10^4	25,000	10^{-13}	10^{16}	10	10^4
2.1	0.8	5.5×10^3	9.8×10^3	1.25×10^4	10,000	10^{-5}	10^{24}	10^4	10^6
2.3	1.0	200	200	5.4×10^3	1,000	0.2	10^{28}	10^7	10^7
2.6	1.3	200	200	ca. 1000	500	0.5	4×10^{28}		
3.4	2.1				≥ 0	0.9	10^{29}		

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[22] Hinshelwood, Kinetics of Chem. Changes in Gaseous Systems, Oxford Univ. Press, p. 12 (1933).

will be distributed individually in the "holes" or positions of minimum potential energy within the crystal, and will be surrounded by a number of like barriers from the adjoining points of low energy. The atom will have a certain chance of migrating to one of these positions as shown in the previous table, but with no concentration gradient and purely random thermal motion, there is a high probability that the atom will be found at its starting point. There is a similar order of probability that it will be found in an adjoining space, and the chance that it will diffuse to successively further separated spaces decreases rapidly with the number of these cells. In a crystal one millimeter in diameter, there would be on the average about 10^6 cells, so that the probability of an atom's diffusing from the centre to the outside of the crystal would be low.

Calculation of Approximate Distances of Diffusion

The average distance that an atom will diffuse in a billion years can be calculated.[23] This distance, $\bar{d}$, is obtained from the expression[23]

$$\bar{d}^2 = t\lambda v \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

$$= \text{time} \times \text{mean length of path} \times \text{average velocity.}$$

This equation is applicable to self-diffusion in gases and in liquids. It might be objected that the application to our present problem is rendered doubtful by the fact that the mean length of the path may exceed the spacing between equilibrium positions. This can arise if there is any "persistence of velocity," that is, if an atom, once it has attained the requisite activation energy, can cross two barriers or more instead of one. If this were the case, we should expect the same phenomenon to occur in liquids, for the packing is not much different from that in crystals except for the randomness and increased mobility of groups, and the moving atom must pass over similar potential barriers. The agreement between calculation and experiment in diffusion of liquids, and in the Brownian movement in colloids indicates that this does not take place to any extent. A similar treatment applied to viscocity[20d] also agrees well with experiment. The activation energy for the translational degree of freedom corresponding to flow over distance λ is one-third the energy required to vaporize a molecule. In some cases of deviations between theory and experiment, it is only necessary to assume that a small percentage of the flowing atoms travel a distance of 2λ instead of λ. Such a correction is unimportant for the present argument, and may be neglected.

The values for the time, path length, and velocity (independent of direction) in an average crystal are:

$t = 10^{16}$ seconds,
$\lambda = 5 \times 10^{-8}$ cm., and
$v = 10^{13}\, e^{-E/kT} \times 5 \times 10^{-8} = 5 \times 10^{5}\, e^{-E/kT}$ cm. sec.,

so that $d = 1.5 \times 10^{7}\, (e^{-E/kT})^{1/2}$ cm.

The distances that an atom could diffuse during geologic time through crystals with different pore sizes are given in the last two columns of Table VII. The calculations are made at 400° K. and 1000° K., to show the effect of temperature on the distribution of thermal energy and on the rate of diffusion.

The above calculations have been based on a rather idealized picture for the purpose of simplifying the treatment. Other complicating factors that enter into the problem can be evaluated with varying degrees of certainty. It is important to determine the effect of vibration of the crystal ions and the distorting power of foreign atoms within the crystal, both of which effects may favor an increased rate of diffusion. Moreover, any departure of the crystal from the perfect structure will leave larger spacings within the mineral and favor diffusion. In the following sections, these and other factors will be considered in order to obtain some idea of the diffusion of helium under the conditions within ordinary rocks.

The Effect of Atomic Vibrations in Crystals

Since the atoms within crystals are always in thermal motion, it is possible that a spacing may momentarily open up enough to allow the passage of a helium atom. The average amplitude of vibration for various conditions may be calculated with sufficient accuracy for this problem from the energy of vibration, assuming simple harmonic motion:

$$E = \tfrac{1}{2}k\,[(R_0 + x) - R_0]^2 = \tfrac{1}{2}kx^2 \ldots (18)$$

where x is the increase over the equilibrium distance, R_0, and k is the force constant, for which an average value of 5×10^5 dynes per centimeter has been selected. Assuming E equal to the average thermal energy, kT, the average amplitude is 4.5×10^{-10} centimeter at 300° K.

Values of the probability P_1, of an atom's having amplitudes of vibration of x or more are given in Table VIII.

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[23] Einstein und Smolukowski, Handbuch der Physik IV, 252 (1929).

Before the size of the hole is increased uniformly by any particular amount, the amplitudes of vibration of all of the atoms bounding the space must be increased by at least that amount. If there are four of these atoms, on the average, the probability of such an occurrence is P_1^4 (last two columns). For example, the chance that all four of the amplitudes of vibration will be increased by at least 0.1 Å is $(6.7 \times 10^{-3})^4$ or 2×10^{-9} at 300° K. The probability that the size (radius) of the hole will be increased by this amount will be less than this, because the chance that all of the atoms will be vibrating in a direction away from the centre of the space at any one instant will be less than one. But for the purpose of finding the maximum effect of vibration, a probability of P_1^4 has been used; then the calculated diffusion of helium due to this factor represents an upper limit.

TABLE VIII

APPROXIMATE PROBABILITIES OF POSSESSING VARIOUS AMPLITUDES OF VIBRATION

x Å	$E = \frac{1}{2} kx^2$ ergs	$P_1 = e^{-E/kT}$		P_1^4	
		T = 300° K.	T = 600° K.	T = 300° K.	T = 600° K.
0.01	1.0×10^{-20}	0.95	0.98	0.82	0.94
0.05	2.5×10^{-19}	0.29	0.53	6.7×10^{-3}	8.2×10^{-2}
0.075	5.6×10^{-19}	6.1×10^{-2}	0.25	1.4×10^{-5}	3.7×10^{-3}
0.1	2.5×10^{-13}	6.7×10^{-3}	8.2×10^{-2}	2.0×10^{-9}	4.5×10^{-5}
0.2	1.0×10^{-12}	2.0×10^{-9}	4.5×10^{-5}	1.6×10^{-35}	4.1×10^{-18}
0.3	2.25×10^{-12}	2.5×10^{-20}	1.6×10^{-10}	1.3×10^{-73}	4.1×10^{-33}

The instantaneous increase in size of the holes will lower the energy of repulsion momentarily, and thus increase the probability of a helium atom's crossing the barrier to an adjoining position of low potential energy. The probability that a helium atom will cross one of these lower energy barriers will depend on two factors, the chance of its possessing the requisite thermal energy at any one instant, and the probability of the hole being increased by that amount at the same time, i. e., $e^{-E/kT} \cdot P_1^4$. It is obvious that the resultant of these two effects will yield a maximum diffusibility at some particular amplitude of vibration, and this will vary with the size of the spacing. The results for holes of various sizes are shown graphically in Figure 15. The minimum in each curve as plotted in this figure corresponds to the minimum height of the barrier for that interatomic distance, and hence to the maximum diffusibility. It is observed from the curves that for a hole of 1.8 Å radius at 300° K, the rate-determining process is that of helium atoms crossing the energy barriers when the atoms bounding the hole are vibrating with an amplitude of 0.1 Å, and the probability of this occurrence is 10^{-36}. Since this represents the maximum effect of vibration, the true curves for different spacings would be displaced upwards, and the minima displaced to the left. The effect of increased temperature is shown by the series of dotted curves.

The Possibility of Distortion and of the Ejection of Helium

In the above calculations it has been assumed that the helium atoms may be in equilibrium in one of the spaces within the crystal, and that since they are so few in number relative to the number of spaces, no internal pressure will be built up.

Comparisons of the size of the helium atom and the spacings within crystals suggest that there must be some repulsion and distortion due to the presence of such a large foreign atom, and while these forces are probably partially distributed between the other atoms in coming to some sort of equilibrium, there might be a tendency for the helium atoms to be expelled from the crystal or to some point where there is more space available. This presupposes a condition of lower potential energy in one of the neighboring positions, and so on to the outside of the crystal, that is, the helium atom must migrate from its equilibrium position to some millions of other points of successively lower potential energy if it is to be expelled from the crystal. Such a process occurring by the mechanism of diffusion through structural spacings has been excluded (although as shown below, this effect may lower the effective size of the potential barriers somewhat), and the only other possibility is that it take place by some sort of exchange or interatomic rotation. The possibility of helium atoms migrating through the crystal may occur to many geologists, because of the common occurrence of similar processes in many minerals. In the phenomenon of "exsolution" common in feldspars and in certain sulfides, two similar compounds originally in solid solution and more or less uniformly distributed throughout the crystal, separate out into lenses or stringers, giving a composite structure of more or less regular arrangement of the two minerals. This effect occurs at elevated temperatures when both substances are present in appreciable concentrations, and are similar chemically and crystallographically, such as sodium and potassium feldspars. This similarity may be the cause of exchange by frequent crossing of the potential energy barriers, and ultimate approach to the stable condition of minimum potential energy for the system, which in this case is the formation of the separate crystals in microperthite. Migration and exchange of similar atoms in this way may take place readily in crystals that have "holes" in their main framework through which the more loosely held cations can travel when their thermal energy is high. This sort of effect would not be expected in the case of helium, for reasons given below, and from the energetics of the problem, discussed in a later section.

It is known from experiment that the helium content is of the order of 10^{-5} cc. per gram in rocks and is not localized excessively. Variations in the amount of helium by a factor of ten in different samples have given the same age, showing no loss, and experiments on radioactive minerals[24] have shown a remarkable retention of helium over hundreds of millions of years, even when the concentration had increased a millionfold, and the crystal structure was undoubtedly distorted by the effects of such excessive concentrations of radioactivity. Helium age determinations by Lord Rayleigh and others on these minerals resulted in "ages" from thirty to seventy per cent of those found by the lead method. That half of the helium has remained in such minerals during geological time is evidence against any tendency of the normal crystal to eject foreign helium atoms when present in moderate concentrations.

Nevertheless, when helium atoms are present within the normal crystal structure, they exert some pressure due to repulsion, and there is a resultant distortion of the immediate molecular environment. This stretching effect of the helium atom on the crystal will lower the magnitude of the potential barriers, thus increasing the chance of escape through structural spacings. Obviously, the effect is not great, because the stretching is limited by similar repulsive potentials arising between the crystal atoms, which themselves tend to resist compression and have interatomic energies dependent on the nuclear separations much as in the case of helium. The atoms within the crystal are in their stable equilibrium positions, being held in position by strong valence, ionic, or intermediate type bonds. Closer distances of approach are opposed by the entrance of high repulsive forces inversely proportional to about R^{12}. It seems reasonable to assume that these crystal units are more incompressible than the helium atom, and that the distribution of energy is such as to lower the barrier by a factor of less than 1/3, the effect being the least when helium is exerting small repulsions in larger crystal spacings. The barriers between the points of minimum potential energy for helium within the crystal have been reduced accordingly to take care of this factor (Table IX, column 2).

Diffusion During Geologic Time

The effect of atomic vibration in lowering the potential energy barriers for diffusion is shown in Figure 15 and in column 3, Table IX. The probabilities for the rate-determining process, obtained from Figure 15, are given in columns 4 and 5.

The extent of diffusion of helium through crystals is obtained by means of Equation 17, where $t = 3.15 \times 10^{16}$ seconds, $\lambda = 5 \times 10^{-8}$ cm., $v = 5 \times 10^5 P$, and P is the probability of crossing a barrier. The mean distance, $\bar{d}$, of self-diffusion of a helium atom in a billion years is then $10^{7.45}P^{0.5}$. Values of $\bar{d}$ for different interatomic distances are given in the last two columns of Table IX for temperatures of 300° K. and 600° K. The interatomic distance is the same as that used previously, being the radius of the smallest sphere that passes through the nuclei of atoms bounding one of the "holes" within the crystal, determined from X-ray data. It is found that the

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[24a] Strutt, R. J., Proc. Roy. Soc. London *84*, 194 (1910).

[b] Strutt, R. J., ibid. *76*, 88 (1905).

[c] Holmes, The Age of the Earth, Nelson Classics, p. 173 (1937).

[d] The Age of the Earth, Bull. 80, National Research Council, p. 293 (1931).

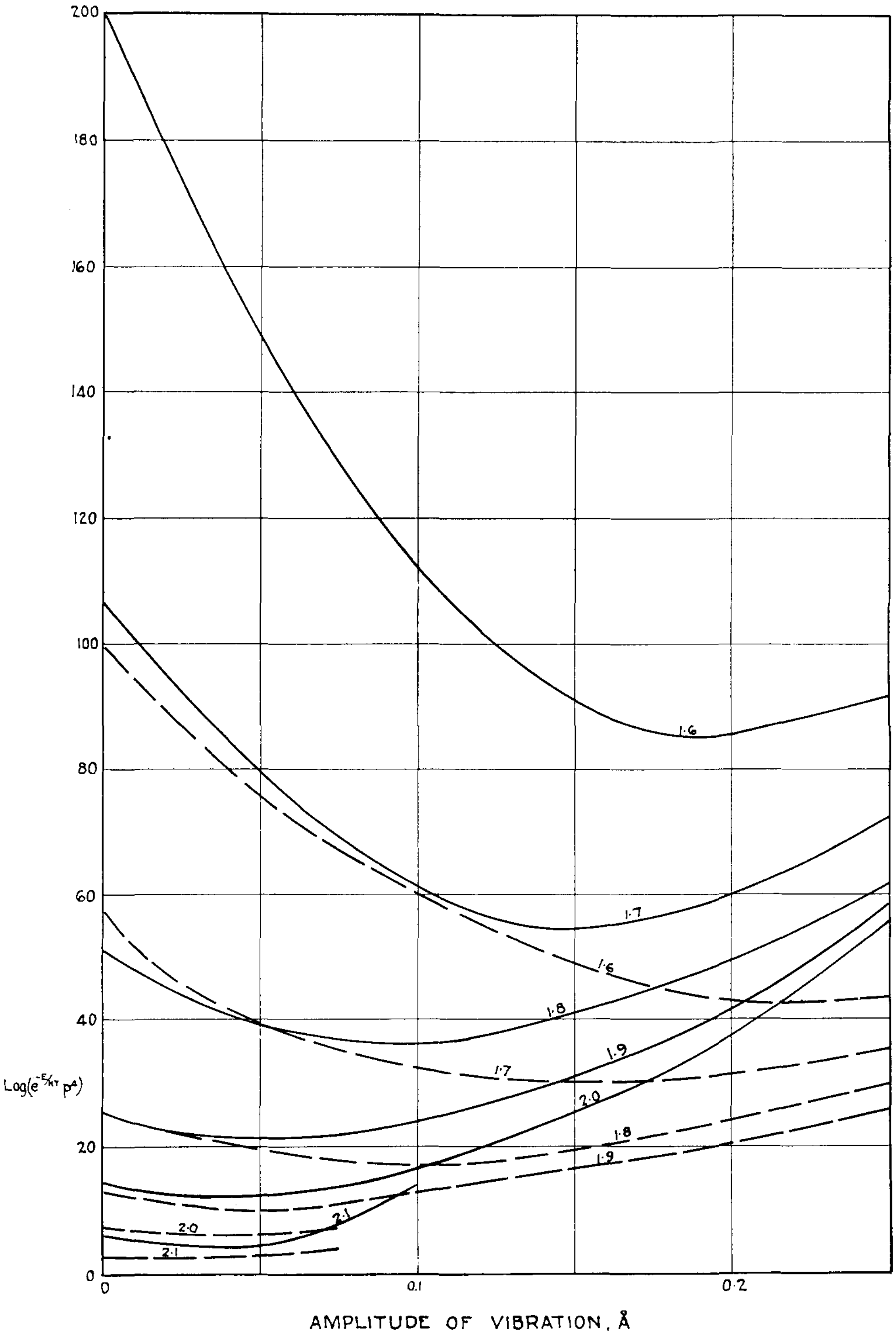

Figure 15. Showing the approximate effect of atomic vibrations on increasing the chance of helium atoms' migrating from one space to the next within a crystal. The probability is given by $e^{-E/kT}P_1^4$. Curves are given for values of R (He-O) from 1.6 to 2.1 Å, and at temperatures of 300° K. (solid curves) and 600° K. (dotted curves).

TABLE IX

APPROXIMATE EXTENT OF DIFFUSION OF HELIUM THROUGH CRYSTALS DURING GEOLOGIC TIME

R, size of spacing, Å	Height of barrier cals. for		Probability of crossing barrier for rate-determining process		Mean distance of self diffusion in a billion years, cm.	
	rigid crystal	increase of 0.05 Å due to vibration				
	T = 300° K.		300° K.	600° K.	300° K.	600° K.
1.4	2.0×10^6	1.3×10^6	10^{-200}	10^{-100}	10^{-93}	10^{-43}
1.5	7.0×10^5	4.74×10^5	10^{-125}	10^{-70}	10^{-55}	10^{-28}
1.6	2.75×10^5	2.0×10^5	10^{-85}	10^{-43}	10^{-35}	10^{-14}
1.7	1.5×10^5	1.0×10^5	10^{-55}	10^{-30}	10^{-20}	$10^{-7.5}$
1.8	7.0×10^4	5.0×10^4	10^{-36}	10^{-17}	$10^{-10.5}$	10^{-1}
1.9	3.5×10^4	2.6×10^4	$10^{-21.5}$	10^{-10}	$10^{-3.3}$	$10^{2.5}$
2.0	2.0×10^4	1.5×10^4	10^{-12}	10^{-6}	$10^{1.5}$	$10^{4.4}$
2.1	1.8×10^4	6.0×10^3	10^{-4}	$10^{-2.5}$	$10^{5.5}$	$10^{6.2}$

effect of oscillation of crystal atoms is to increase the diffusion considerably, the maximum effect being at displacements of 0.05 to 0.1 Å. For purposes of diffusion considerations involving an appreciable activation energy, then, the effective size of the hole in the average crystal should in general be increased by about a tenth of an Ångstrom unit.

The average distance of diffusion of a helium atom in a billion years is plotted in Figure 16 as a function of the internuclear distance. Curves 1 and 4 are plots of the data given in the last two columns of Table IX, giving a maximum for the extent of diffusion at 600° and 300° K., respectively. Curves 2 and 5 are plots of the diffusion data given in the last two columns of Table VII, at 1000° and 400° K. respectively, and show the distances of diffusion calculated on the rigid crystal model. Assuming that the activation energies are correct, the true curve at 350° ± 50° K. would be somewhere between curves 4 and 5. There is little difference in the point where this crosses the abscissa of zero diffusion, and no diffusion of helium would be expected at values of R lower than 1.97 Å. Curve 3 was calculated for a temperature of 600° K., taking a force constant of 1×10^5 dynes per cm., and a probability of P_1^{10} that all of five atoms bounding a spacing are vibrating so as to have uniform stretching.

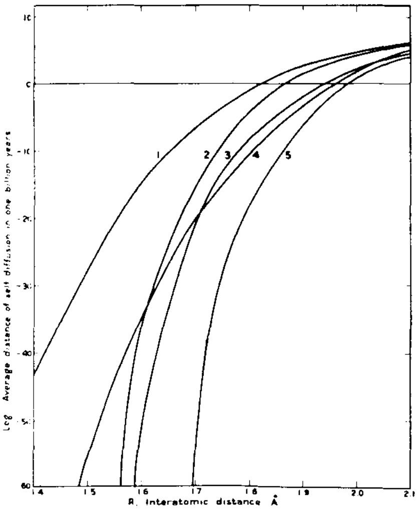

FIGURE 16. Calculated average distances of self-diffusion (log-cm.) during geologic time, at various interatomic distances (He-O).

1: Maximum values at 600° K. with probabilities from Figure 15.

2: For the rigid crystal model, at 1000° K.

3: Values at 600° K., using a probability of $e^{-E/kT}P_1^{10}$ and force constant of 10^5 dynes per centimeter.

4: Calculated in the same way as curve 1 at 300° K.

5: Calculated in the same way as curve 2 at 400° K.

While the diffusion calculations are only approximate, an effort has been made to choose values that would give a maximum rate of diffusion wherever there was any flexibility. Since it will be shown later that the effect of temperature for rocks below the earth's surface is approximately compensated by the effect of pressure, 600° K. is considered to be satisfactory for the purpose of obtaining an upper limit for the diffusion of helium in rock minerals. An inspection of the curves in Figure 16 will show that this limit for the escape of helium atoms from crystals through self-diffusion is found to be $R = 1.82$ Å, or where oxygen ions ($r = 1.32$) are the predominating unit in the rigid structural model, through a hole 0.5 Å in radius. This is larger than any spacing in perfect crystal structures of many rock minerals.*

Notes on Spacings in Common Rock Minerals

Alpha-Quartz. The atomic packing model of alpha-quartz is shown in Fig. 9. The photographs were taken to show the largest channels in the crystal, rather than other details of structure, so that all of the visible atoms are of oxygen, the silicons being hidden at the centres of oxygen tetrahedra. The tedious construction of such a model was carefully carried out from X-ray data by Buerger and co-workers. Similar models for the other minerals discussed are also shown in this figure. The interatomic distances in alpha-quartz are:[25]

Si–O: 1.61, 1.62, 1.60, and 1.62 Å;
O–O: 2.62, 2.64, 2.64, and 2.67 Å.

The largest hole is about 0.6 Å across, so that the interatomic distance between an oxygen ion and an atom would be: $R = 1.65$ Å. With some distortion this might be increased to 1.75 Å. It is interesting to note that if the oxygen ion were imagined as incompressible the radius of the largest atom that could pass through would be $1.75 - 1.32 = 0.43$ Å.

Feldspars. A more or less open "silica net" structure similar to that of cristobalite forms the basis of the space lattices of the feldspars, zeolites, etc. In the feldspars the "holes" occurring regularly in the net structure are filled, most commonly by the ions of K, Na, and Ca; when models are constructed (Fig. 9), it is found that this effectively closes up the structure and leaves relatively small spaces between the K and O ions. It is found, though, that the effective radii of the alkali ions are larger than they are in many other crystals, and that they are capable of interchanging positions at higher temperatures because of being held less firmly within the crystal structure. Since the silicon and aluminum ions are "hidden" in the centres of oxygen tetrahedra, their interatomic distances may be neglected. In sanidine[5e, 26] the interatomic distances for O–O vary from 2.55 to 2.95 Å, and there are six oxygens at 2.85 Å and four at 3.1 Å from potassium ions. In constructing the model it was found[27] that, while Taylor's geometry of the crystal required a radius of 1.60 Å for potassium, the somewhat idealized model required 1.72 Å. The size of the largest hole in the (cleavage) plane of the potassium ions in the close-packed structure is 0.64 Å, so that using 1.25 Å[25], the value of R for an atom in the space would be $1.25 + 0.32 = 1.57$ Å, or using the average size of the oxygen, 1.64; or with 1.60 Å for K, 1.76 Å. The effective size of the "hole" may be increased somewhat at high temperatures because of the mobility of the alkali ions along the cleavage planes.

Pyroxenes and Amphiboles. The entrance of several other cations into the silicon-oxygen net structures results in a much more compact structure than in either feldspar or quartz, and in the blocking of all "channels." There is a possibility of only restricted motion of a small atom in certain spaces. The average X-ray interatomic distances for diopside[27, 28] are Ca to eight O, 2.35 Å; Mg to six O (2.10 Å); and O to O, 2.7 Å. The maximum value of R would be about 1.6 Å. From the standpoint of compactness one would expect that the greatest probability of retention of helium would be in this class of minerals.

Mica. The crystal structure of micas is similarly close-packed, except for a plane or sheet which repeats itself at about every four "rows" of oxygen atoms. The cleavage takes place through the potassium planes. The average width of these sheets in muscovite[27, 29] mica is about 3.0 Å, so that R would be 1.5 Å. From the model[25] (Fig. 9) the maximum diameter of a channel between the assumed surfaces is about 1 Å, corresponding to $R = 1.8$ Å.

Zircon is of interest because of its common association with radioactive atoms and pleochroic halos. The structure (Fig. 9) is close-packed, and has no large channels.[5e, 30] The interatomic distances are: Zr–O, 2.05 and 2.41 Å; O–O, 2.6 Å. The distance R from the centre of an oxygen atom to the centre of the largest spacing is 1.6 Å, too small to permit diffusion through the normal structure.

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* Experiments by sensitive radioactive methods just published by Hevesy and co-workers (Trans. Far. Soc. pp. 841–849, August, 1938) indicate the correctness of the above calculations. It was found that high activation energies (30 to 50 kilocals) were required for the diffusion of lead in lead, lead chloride, and lead iodide, and for the self-diffusion in gold. Hevesy calculated that the diffusion would be less than a millimetre in one and a half billion years.

[25] P'ei-Hsiu Wei, Z. Krist. *92*, 355 (1935).

[26] Taylor, Z. Krist. *85*, 425 (1933); *87*, 464 (1934).

[27] Dorris, Frondell, Güssow, Lopez, Lord, Parrish, and Shimer, Am. Min. *23*, 65 (1938)

[28] Warren and Bragg, Z. Krist. *69*, 168 (1928); Strukturbericht II, 130 (1937).

[29] Jackson and West, Z. Krist. *76*, 211 (1930); *85*, 160 (1933); Strukturbericht II, 144 (1937).

IV. CRYSTAL IMPERFECTIONS AND OTHER FACTORS

Crystal Imperfections

The previous discussion has led to the conclusion that helium atoms cannot escape from most perfect crystals because of the close-packed nature of the mineral structures. This does not preclude the possibility of diffusion through channels arising from imperfections in crystal growth. There are both theoretical and experimental evidences of a little disorder in most crystal structures, and the problem is to decide how important are such effects in allowing the escape of helium. These may arise during growth, from cracking of crystal surfaces or from the deformability resulting from the substitution of different sized ions in solids. The presence of contraction cracks on crystal surfaces has been suggested by Griffith[31] to explain the subnormal experimental strength of various solid mixtures, both crystalline aggregates and glasses, and has been predicted theoretically by Jones and Dent[14] in accounting for the surface tension of the surface layer. Smekal[32] and Zwicky[33] have elaborated these theories of surface flaws to explain the development of Ewald's mosaic crystals, the surface cracks continuing on, and influencing the orientation of incoming molecules during rapid crystallization, so as to give finally a crystal made up of block-like units.

In addition to their formation from the cracking of the surface from surface tension, crystal imperfections may also arise from the deformation resulting from the substitution of ions of different sizes in solid solutions. These theories have been put on a more fundamental basis in the "lineage growth" theory of Buerger,[34] which accounts satisfactorily for many mineralogical data. After the growing crystal reaches a certain degree of distortion, surface breaks will form, and the crystals will grow along different branches, giving rise to the lineage growth common in certain sulfides. A schematic illustration of the phenomenon is shown in Fig. 17. Evidence for some sort of mosaic imperfections in most crystals is obtained from the variations between calculated and experimental intensities of X-ray reflections. Many of these imperfections will be represented by continuous channels to the crystal boundary, but in other cases the surface cracks are closed by the deposition of other layers during rapid crystallization, as illustrated in Fig. 18, so that no avenue of escape for helium remains. During slow crystallization these cracks may be the origin of lineage boundaries. Whether or not diffusion will occur through any channel will be dictated by its width and the corresponding energy considerations discussed previously (Fig. 11), but it will be interesting for the moment to assume that all of them are large enough for the passage of helium atoms, and so obtain a maximum estimate for helium loss from this factor.

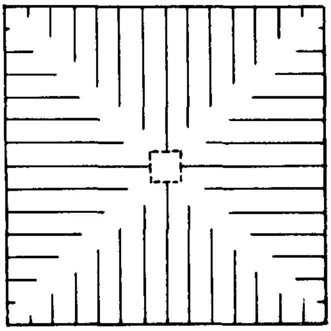

FIGURE 17. Two-dimensional analogue of a cubic crystal subdivided into lineages (after Buerger), highly diagrammatic. All lineages in later crystal growth have descended from the central nuclear cube. Such parallel peripheral lineages may often be seen in galena.

To do this, the minimum distance between the wedge cracks which form to relieve contraction strains must be obtained. The surface will be at equilibrium at that configuration of ions which possesses a minimum potential energy. Two ions of like size cannot come into vertical contact in the first and second layers, because this would increase the potential energy. This fact at once governs the surface spacing and the minimum separation of checks (Fig. 18). Because of the simplicity of analysis, most of the work has been done with simple ionic models, and in particular, with sodium chloride. Smekal, Zwicky, de Boer,

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[30] Wyckoff and Hendricks, Z. Krist. *66*, 73 (1927).

[31] Griffith, Proc. Int. Cong. for App. Mech. I, 55–63 (1925) (reviewed by Zwicky).

[32] Smekal, Zeits. techn. Physik *7*, 535 (1926); *8*, 561 (1927).

[33] Zwicky, Proc. Nat. Acad. Sci. *15*, 253 (1929).

[34] Buerger, Am. Min. *17*, 177 (1932).

and Lennard-Jones and Dent all agree that the spacing in this case is not less than 100 Å. The figures deduced by Zwicky for sodium chloride are given in the dimensions of Fig. 18.

Some loss of helium will occur through these surface cracks. The amount lost will be directly proportional to the volume of the cracks compared to the volume of the crystal as a whole, on the assumption that only those alphas whose paths end in such cracks will have an opportunity of escape. These are obviously very few. Using Zwicky's figure, the loss due to this factor would be only 2×10^{-14} per cent for a crystal one cm. square, a quite negligible amount. Actually, the cracks are probably far from being so numerous on the surface during crystal growth from mineral solutions, as most of the surface strain is absent because of the small potential energy gradient from the crystal through a film of saturated solution to the main body of the liquid solution. The spacings in ordinary permanent dry surfaces of NaCl given above were deduced from several facts one of which is that the experimental strength of salt increases considerably when pieces 10^{-5} to 10^{-6} cm. in size are used. In larger crystals, the presence of cracks reduces the strength enormously over that calculated theoretically. Similarly, wetting the surface causes a remarkable increase in tensile strength, which *indicates a large increase in the spacing* between cracks when in contact with solvent.[35] Buerger has cited further evidence of this phenomenon in connection with lineage growth (which may arise from these cracks), and finds the interlineage boundaries to be quite widely separated—of the order of millimeters, and quite easily measureable.[34]

In rock minerals the degree of imperfection would be expected to be small, and the lineage boundaries further apart, because of the near equilibrium conditions of very slow crystallization. Nevertheless, it will be interesting to estimate the number and volume of channels formed by such boundaries. The data and figures given by Buerger for galena may be used, and the number obtained from a simple extension of Fig. 17 to the third dimension using four sets of regular lineage sheets. For the purposes of calculation, sixteen parallel lineage boundaries have been taken, 0.4 millimeters apart, in a crystal cube 0.64 centimeters long. If the widths are taken as 4 Å, the volume is about 2×10^{-6} cc., so that the

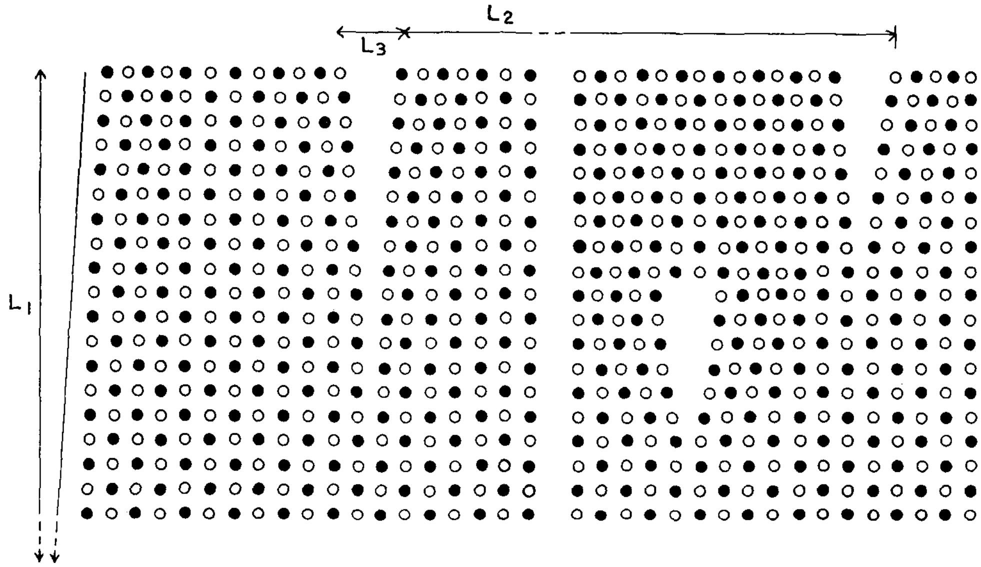

FIGURE 18. Crystal imperfections in a cubic crystal, highly diagrammatic. (After Buerger and Zwicky.) The size of the cracks forming through strain at crystal surfaces or from impurities is limited by the fact that any contraction must not bring an ion in one plane opposite one of like sign in the next plane. In the lower right corner is illustrated the closing of a contraction crack by later growth. The dimensions given by Zwicky are: L_1, about 50 Å; L_2, about 100 Å; L_3, about 8 Å.

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[35] Joffé, A. F., Trans. Far. Soc. *24*, 65 (1928).

fraction of helium formed in these channels is about 0.0007 per cent. Buerger states that one of the characteristics is that the lineage crystal is continuous, and does not suffer sudden breaks. Any irregularities would increase the above estimate. In order to obtain some sort of upper limit, it may be assumed that the imperfection boundaries occur about every 500 Å.[34, 36] The width of these channels cannot be very large and still leave each block an integral part of the crystal, because even the van der Waals forces would not allow a greater separation than about 4 Å. With this value, and using a cubic crystal 1 mm. to a side, the total volume of the imperfection sheets would be 2.4×10^{-5} cc., giving an upper limit of 2.4 per cent of the helium escaping. However, it is probable that in addition to the small loss through imperfections arising from lineage growth, migration of helium may occur also due to inclusions, intergrowth, strains, and other factors, and in some crystals these effects might conceivably be great enough to allow only a partial retention of helium. It might be interesting to perform diffusion and X-ray experiments on two crystals, one which exhibited considerable lineage growth or possessed other imperfections, and another crystal of the same mineral that was proven to be perfect as far as X-ray and goniometric measurements are concerned.

In metals and some ionic crystals, the vacancies caused by imperfections in crystal growth may migrate through the crystal due to the tendency of adjacent ions to fill the space. Such shifting of position may occur also with foreign ions, so that a gradual change in the relative orientation of the interstitial atoms, i. e., diffusion, takes place. In silicates, owing to the high bond energies and the restrictions on the spatial arrangements of the bonds, this effect is not considered important once the crystal is in thermodynamic equilibrium.

The Passage of Helium through Interstices

Rayleigh[37] observed that highly polished Hilger glass plates, adhesed to contact, permitted the diffusion of helium. In the preparation of the plates, the temperature was allowed to rise to adhesion but not high enough to destroy the optical flatness. The average distance between the plates was less than 7 Å, and probably greater than 3 Å. The ratio of helium to air transmitted was 6.8 : 1, whereas the densities are 2.7 : 1, indicating that repulsive forces with the consequent activation energies enter even at these interatomic separations, and these are less for helium than for nitrogen and oxygen (1.4 Å).

In experiments on rocks, it was found[38] that helium diffused through a fine-grained basalt under a high concentration gradient. Since other experiments show no indication of diffusion through single crystals, even with high temperatures and a month's time, and since the diffusion in rocks followed the law of capillary flow, it appears that helium must pass through the interstices between the crystals in rocks. The question arises as to how much loss of helium would occur by diffusion down the channels. The channels are probably of the order of a few Ångstrom units, judging by the diffusion rates, and they are certainly beyond the range of detection microscopically. Examinations of several rocks with the Graton precision microscope showed only an insignificant number of cracks in the minerals, while all of the minerals were ordinarily in close contact with their neighbors.

Since the helium is present to only about one part in 100,000, it is unlikely that many helium atoms would be surrounded by others at any point between crystals, so that the concept of a gradient in the concentration of helium cannot be applied, and there would probably be very little driving force towards diffusion. The previous calculations show that diffusion takes place extremely slowly for isolated atoms. Of the emitted alpha particles in rocks, only those whose paths end in a channel would form helium in the interstices, and these would have a certain chance of escape. The fraction of helium atoms formed in these channels will be directly proportional to the volume of free space between crystals, since the alpha particles are emitted at random.

Some idea of the degree of imperfection and of the size of the interstices may be obtained from compressibility data. It is found that the volume change is greatest at the first increase in pressure; at higher pressures it decreases and approaches a constant value. The initial increase in compressibility is presumably due to the compression of the free volume between crystals and in crystal imperfections, and this is precisely what is needed for the present problem. This volume has been obtained also by forcing mercury into the rock under high pressure. Both methods show

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[36] J. H. de Boer, Trans. Far. Soc. *32*, 54–69, 1936.

[37] Rayleigh, Proc. Roy. Soc. London *A156*, 350 (1936).

[38] Urry, J. Am. Chem. Soc. *55*, 3242 (1933).

that it is only 0.2 to 0.4 per cent of the volume of the rock. It is a little greater in coarse granitic type rocks than in diabases. These experiments give results somewhat lower than those from porosity determinations. The values collected by Daly[39] are for granite (5)*, range of porosity 0.3 to 2.6 per cent of the rock; for gabbro (1), 3.0 per cent; for basalt (2), 0.4, 0.5 per cent; for diabase (3), 0.2 to 1.2 per cent; and for gneiss (3), 2.5 to 4.4 per cent of the rock. The alpha particles will be emitted at random in all directions, and if the radioactive materials are distributed fairly uniformly and no diffusion takes place through the structure, the maximum fraction of helium atoms that can escape is given by the porosity, which is the ratio of the volume of the interstices to the volume of the rock as a whole. The range given in the above experiments is from 0.2 to 3.0 per cent, not large enough to affect seriously the helium age.

There is a possibility of additional helium atoms reaching the interstices through strains set up in the decay of radioactive atoms, but as shown later this is not expected to occur to any great extent, for when the local concentrations of radioactivity are well within the mineral, the crystal may be readjusted to strain within a short distance. The ideal case for maximum retention is that of random distribution of the radioactivity. In practice, it is probable that some of the radioactive material is localized within crystals, and it is important to obtain more definite information on this point, both as to how extensive is the localization and how great is the repulsive force compared to the forces of cohesion within the crystal.

The Distribution of Helium in Rocks

Experimental evidence indicates that all minerals show some radioactivity, although it is sometimes in greater concentration in certain kinds of minerals than in others. Such variations have been noted by several observers, and while no general relation has been found as to the distribution,[40] there is certainly no evidence of there being any excessive local concentrations. The study of the distribution of radioactive crystals or atoms throughout rocks is difficult petrographically because of the minute quantities present and the limitations in the resolving power of the microscope. Even the Graton precision microscope has a limiting resolution of about 1000 atoms. The study by direct analysis of the distribution of radium, thorium, and helium in individual rock minerals has already been commenced, and results on several rocks appear elsewhere.

If there were localization of radioactivity in the interstices and imperfections in rocks, or concentration at the surfaces of crystals, errors would enter into helium age work. Such a distribution has not been observed petrographically, although Piggot found some evidence of such localization in one granite.[40a] Inclusions within crystals and pleochroic halos are generally found to be distributed more or less at random throughout the larger crystals. Ordinarily, the nuclei of pleochroic halos are difficult to discern. When the mineral is identified, it is commonly found to be zircon, allanite, or a similar mineral with a relatively low percentage of uranium and thorium. The size of the visible inclusions is found to be about one or two microns. Joly and Rutherford and Holmes considered that it would be safe to assume ten per cent of uranium as an upper limit for the amount now contained in the nuclei of the halos.[41] Even if all of the nuclei of the pleochroic halos in biotite were pure uranium, they would still not account for even a small fraction of the measured amount of radioactivity; there would have to be the order of a billion halos per gram. It is obvious that the bulk of the "inclusions" are invisible and it seems likely that many radioactive atoms are distributed at random as minute contaminations throughout the atomic network.

An experiment by Urry[42] has shown that the same helium content was obtained from a single piece of rock, from a few pieces of the same weight, and from a fine powder, and that no loss occurred when rocks were allowed to stand in a vessel with helium-free oxygen for three months. These experiments would indicate the absence of helium in the interstices, and its retention within the individual crystals. Further work on all of these points is to be undertaken within the near future.

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[39] Daly, Igneous Rocks and the Depths of the Earth, McGraw-Hill, p. 52 (1933).

* The numbers in parentheses refer to the number of determinations.

[40] Evans and Williams, Am. J. Sci. *29*, 441–452 (1935), (includes review).

[40a] Piggot, C. S., Am. J. Sci. *17*, 28 (1929).

[41] Joly, J., and Rutherford, E., Phil. Mag. *25*, 644–657 (1913). Holmes, in Bull. 80, Nat. Research Council, p. 190 (1931).

[42] Urry, Chem. Rev. *13*, 305 (1933).

Possibility of Crystal Rupture through Radioactive Decay

The crystal structure of radioactive minerals must be badly shattered by radioactive decay, for in a mineral 500 million years old seven per cent of the uranium atoms will have disintegrated, liberating a large amount of energy, and leaving in place of each, eight helium atoms and one lead atom. This renders the mineral susceptible to alteration and selective leaching of lead and radioactive atoms, and permits a partial escape of helium. The situation in ordinary rocks is quite different, for the concentration of uranium and thorium may be only a millionth of that in a radioactive mineral, and both are commonly distributed more or less at random through fresh compact crystalline rocks. The average uranium and thorium content is about 10^{-5} to 10^{-6} gram, and the volume of helium 10^{-4} to 10^{-5} cc., per gram of rock. With such minute concentrations, the effect of disintegration would be only locally important around radioactive loci separated by large molecular distances, exerting the minimum strain in a mineral for the case of random distribution. It is difficult to evaluate the effects of disintegration, because little is known about the changes in the immediate crystal environment, and no accurate data on the tensile strengths of individual crystals are available. But some idea of the strains set up can be obtained from some simple calculations, and from experiments on powdered rocks and radioactive minerals.

The average numbers of atoms disintegrating in geologic time are given in Table X, together with volume requirements and other pertinent data.

The increase in volume was calculated from the approximate equilibrium sizes of the atoms or ions before and after disintegration, assuming the radius of thorium 1.4 Å, of uranium 1.9 Å, of lead and helium 1.0 Å. While these calculations give only approximate values, they at least show that the excess volume required for the disintegration in rocks is negligible, while in radioactive minerals it may be of the order of one per cent. For purposes of comparison, the calculations have been made also for an extreme case of a large inclusion, 10,000 Å across, containing thirty per cent thorium and ten per cent uranium, and here the local volume requirement is 10^{-15} cc. This expansion could be taken care of if the space between the inclusion and the adjoining crystal structure were only 2 Å. It is interesting to note in passing that the pressure of 4×10^{-5} cc. of helium in the volume occupied by one gram of rock would be only 10^{-4} atmospheres.

On the usual assumption of atomic dimensions, the free volume between atoms in the crystal may be calculated to be 40 to 50 per cent; this would suggest that the helium is not exerting any appreciable internal pressure. Using an average value of 5 Å per cell, there would be 3×10^{21} of these cells to 10^{15} helium atoms, so that each atom has three million possible spaces. With this small number of spaces filled, it is likely that some helium atoms are isolated and without influence on one another. However, as already mentioned, the presence of pleochroic halos indicates at least some localization of the radioactivity and hence also of the helium. Since these are commonly within the body of the crystal, there would have to be loss either through some sort of channel leading from the radioactive loci as discussed below, or else through the body of the crystal.

TABLE X

EXTENT AND EFFECTS OF RADIOACTIVE DECAY IN 500 MILLION YEARS

Substance	No. of atoms per gram	No. of atoms disintegrating	No. of atoms helium	Resultant increase in volume if free to expand	No. of atoms disintegrating in inclusion 10^{-4}cm. across	Increase in volume if free to expand
Th	2×10^{16}	5.2×10^{14}	3.1×10^{15}	7.5×10^{-9}cc.	5.8×10^{7}	9.0×10^{-16}cc.
U	7×10^{15}	5.5×10^{14}	4.4×10^{15}	2.5×10^{-9}cc.	6.1×10^{7}	3.0×10^{-16}cc.
AcU	5×10^{13}	2×10^{13}	0.14×10^{15}			
Total for rock	10^{22}	1.1×10^{15}	7.6×10^{15}	3×10^{-6}%		0.2% (for the inclusion)
Radioactive mineral	10^{21}	10^{20}	$10^{20.5}$	1%		

The latter reduces to the problem already discussed unless there is a high concentration of helium.

It would appear that even without assuming any rearrangement in the environment after disintegration, the strain built up in ordinary rocks where the activity is low is insufficient to cause rupture. Calculations can be made of the repulsive force, F, from the relation,

$$F = \frac{\delta E}{\delta R} = \frac{bn}{R^{n+1}} \quad \ldots\ldots\ldots\ldots (19)$$

When this is done for thorium, R turns out to be 1.9 Å, and using values of n and b as for Fig. 6, it may be calculated* that the force is about 300 Kg. per mm.[2] This is the order of magnitude of the calculated tensile strength of sodium chloride, which is no less than 200 Kg. per mm.[2] No reliable experimental data exist for quartz or other common minerals; values approaching the calculated values of the strength of sodium chloride have been obtained in some experiments, but for various reasons are difficult of interpretation.[35, 36] One difficulty with attempting to reconcile theory and experiment in these cases, or in the application to the present problem, is that the theoretical calculations are made on the basis of a perfect crystal structure, while in practice rifts may occur along the lineage imperfection boundaries. Since the maximum force calculated above is about the lowest calculated strength for sodium chloride, it indicates that it is insufficient to rupture quartz, but there is the probability that it may form cracks along the cleavage planes of feldspars and micas. This is a question that requires further investigation. In ordinary rocks it may not be important, especially if no local concentrations exist, and it is probable that the spatial requirements may be fulfilled in the rearrangement after the alpha emission. Exactly what does happen during disintegration is still a matter of speculation, but that the entire environment in the immediate vicinity of some radioactive inclusions is changed can be observed visually in the darkened halos in the surrounding crystal.

Some loss of helium may occur due to the crystal imperfection of surface layers, and from those alpha emissions that cause distortion of the surface by the disrupting effect of ionization towards the end of their path. The ionization in the first part of the path is relatively small, increasing to a maximum near the end of its range, as proven by direct experimental measurements of the ionization produced in gases, and from the dark concentric rings of pleochroic halos. As the effect of the fast-moving alphas is probably largely to ionize atoms and raise them to excited states, and not dissociation, the distortion from this factor is probably small. Even if it is assumed that throughout the whole path the crystal structure is changed sufficiently to cause the escape of those helium atoms formed from alpha rays traversing surface layers, the effect is small for crystals of average size. The average range of the alpha particle in rocks is about 1.7×10^{-3} cm. If it is assumed that the radioactive atoms are distributed uniformly and that all of the helium atoms formed within 0.0017 cm. of the surface have a chance of escape, this amount is only one-half per cent for crystals 1 cm. in size, five per cent for crystals 1 mm. in size, and forty per cent for crystals 0.1 mm. in size. Spurious results might be expected in fine crystals, since this surface effect would be proportionately greater. It may be significant that relatively high age results have been found for fine-grained basalts, indicating that this effect is unimportant.

It is likely that the channels formed by radioactive disintegration are almost entirely within crystals (around minute radioactive inclusions). The previous calculations indicate that an opening to a crystal boundary more than 1.4 Å wide would be required before there was any possibility of escape. This is illustrated by a contour diagram of the potential energy within such a crack in Fig. 19. The cross marks the position of a helium atom at one of the equilibrium positions in the channel; it is prevented from escaping by high potential energy barriers.

While it does not seem likely on the basis of this discussion that the minute quantity of radioactivity in ordinary rocks is sufficient to disrupt individual minerals, it is desirable to have more information on this point. An indirect way of attacking the problem experimentally is to consider a case where the degree of localization or concentration is enormously greater than that found in ordinary rocks. Such is the case in radioactive minerals. Since the distortion here may be a million times as great, almost a complete loss of helium in geologic time might be expected. It is significant that experiments by

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* This force calculation was for the extreme case of seven atoms in the space originally occupied by the thorium ion, and may be lowered considerably in the distribution of the radiogenic atoms over 0.02 mm., the average range of the alpha particle.

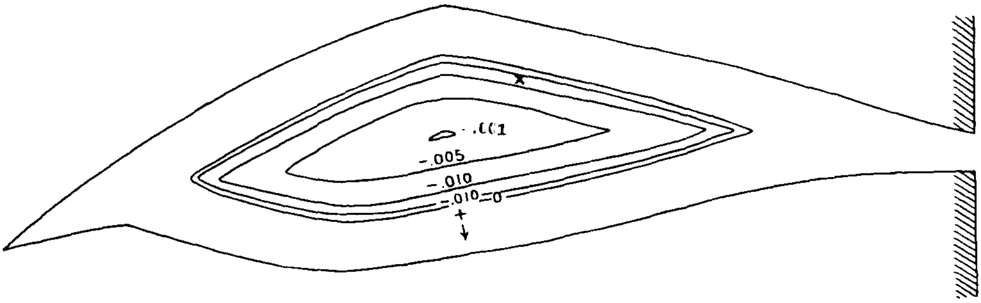

FIGURE 19. Potential energy contours for helium in a channel. *X* marks one of the equilibrium positions. The atom is prevented from escaping through the opening by the high potential energy barriers. The potential energy increases so rapidly in the direction shown by the arrow that the contours are not continued. The numbers refer to electron volts.

Lord Rayleigh showed that often fifty to seventy per cent of the helium had remained in these minerals. Some of his results on minerals with high helium contents are shown in Table XI. It will be observed that even Archean minerals have retained a considerable portion of their helium.

That so much of the helium has been retained in such minerals is indirect evidence for the retention of the minute quantities of helium in ordinary rocks. In radioactive minerals the concentrations are large, the helium exerts a high internal pressure, and the crystal structure is shattered by radioactive disintegration, all of which factors would lead one to expect an even greater loss of helium than has been observed. Lord Rayleigh did find that the rate of escape from the specimen under various conditions in the laboratory was always greater than the rate of production of helium,[43] and concluded that "the conditions under which the normal life of the mineral has been mainly passed, deep down in the earth, where atmospheric agencies have no place, must be supposed more favorable to the retention of helium, for otherwise the present accumulation could never have been formed." That the helium has not diffused into the surrounding rock indicates the impermeability of rocks to helium. This is in agreement with the previous calculations for crystals, but it indicates further that diffusion through the interstices between crystals may also be negligible under the high pressures within the earth, and the results of compressibility measurements show that this is due to the fact that even moderate pressures effectively close up the free spaces between crystals.

Possibility of Compound Formation

The available experimental evidence shows that compound formation is quite negligible for the case of helium in rocks and minerals, but for the sake of completeness the literature on the formation of transitory helium compounds will be considered briefly. While ordinary helium does not form compounds, excited helium may react to form several rather unstable compounds.

TABLE XI

RESULTS SHOWING QUANTITIES OF HELIUM RETAINED IN SOME PRECAMBRIAN RADIOACTIVE MINERALS

Mineral	Helium cc./g.	Uranium g./g.	Thorium g./g.	He Age M. y.	Lead Age M. y.
Thorianite, Ceylon	9.3	0.208	0.575[a]	230	470 to 595[c]
	7.8	0.111	0.638[a]	250	(120 to 375[c], Thorite)
	8.9	0.110	0.676[b]	275	
Gadolinite, Ytterby	2.45	0.025	0.075	480	990[d]

[a] Strutt, R. J., Proc. Roy. Soc. London *84*, 194 (1910).
[b] Strutt, ibid. *76*, 88 (1905).
[c] Holmes, The Age of the Earth, Nelson Classics, p. 173 (1937).
[d] The Age of the Earth, Bull. 80, National Research Council, p. 293 (1931).

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[43] Strutt, Proc. Roy. Soc. London *82*, 166 (1909).

When one of the electrons is raised to another quantum level by the absorption of 19.75 electron-volts, compounds are formed with He, H, Hg, Pd, Pt, I, S, and P. Since a high energy is required, such compounds are formed only in a spark discharge, usually at high temperatures.[44] While some compounds might be formed by the high-energy alpha particle, it is doubtful if they would ordinarily have any more than a transitory existence.

In some cases helium can be held within the structure in a certain position, and in this sense may be considered as combined. The total volume of free space available in different minerals can be calculated from the composition and density, combined with the usual assumptions of ionic radii. The minerals for which these calculations were made fall roughly into the following groups: quartz, orthoclase, albite, anorthite, biotite, riebeckite and apatite, 50%; muscovite, hornblende, and anatase, 43%; diopside, augite, aegirite, and magnetite, 39%; and zircon, titanite, and rutile, 35%. For comparison, the free space in a glass, vitreous silica, is 59%.

The free space calculated in this way may be used for comparing the relative degrees of packing in different minerals; but not all of this space is available for helium or other foreign materials, because of the entrance of repulsive forces, and the essential spherical symmetry of atoms. As pointed out above, this type of consideration may not be very important in the case of helium because of the fact that the immediate atomic environment is altered by radioactive disintegration, and this would presumably provide more space for foreign atoms. It is interesting to complete free space calculations to obtain the maximum quantity of helium that can be retained in a simple cubic atomic framework in which the radii of close-packed atoms are 1.5 Å. With such an arrangement approximately 40 per cent of the free space might be available for helium between the oxygen atoms. Since the total free space is about 50 per cent of the crystal, this leaves 20 per cent of the total volume available for helium. In rocks, the volume of helium present at N. T. P. is about a hundredth of one per cent of the volume of the rock. It was shown above that about one in 10^6 spaces are filled with helium atoms. From these considerations it would appear that there can be no tendency to escape from the packing factor alone.

Diffusion and Replacement Processes

The previous considerations have a bearing on many important geological phenomena. Inclusions of the mother liquor may be present in the cavities produced by imperfections in growth. These may later be filled or, replaced by other material, be the loci of new reactions. The ingress of foreign solutions may take place through submicroscopic channels resulting from some sort of peculiarity of growth, and not at random through the crystal. Those ions that can enter the crystal in this way must be below a certain limiting size governed by the repulsive forces of the walls. These forces will vary for different kinds of ions, but will be identical in principle with those discussed in connection with helium atoms. Metasomatic processes may commence along surface cracks and lineage boundaries, and will take place the most readily in the most imperfect crystals or the most porous rocks. The best example in rocks is the preponderance of contact phenomena and metasomatic mineral deposits in porous limestones and dolomites. "Replacements" in some crystals, such as some of the cinnabar in the Almaden quartzite[45] and other examples where the original or host crystal retains its perfection of form, have given the impression that the atomic network is permeable to these foreign atoms, but this may not be strictly true because the reaction may proceed along relatively very few channels of molecular dimensions, and in perfect crystals would not occur at all. In the above example, some of the cinnabar stringlets apparently were formed in the channels leading from the interstices between crystals, while in others the cinnabar nucleus probably started in cavities which originated in crystal distortions during growth. The observed tendency towards parallel orientation of the veinlets and lenses in the quartzite grains suggests the entrance of the sulfide solutions along oriented imperfections caused by metamorphism, probably parallel to the c-axis.

In feldspars the familiar alteration of the core higher in calcium content seems to occur along growth imperfections or channels arising from sudden changes in the proportions of incoming ions. Alteration along such zonal boundaries is common, and the core alteration may often be traced to the ingress of foreign solutions along them.

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[44] Damianovitch, C. A., Sci. Progress *31*, 282–6 (1936); *30*, 2064 (1936).

[45] Description and illustration after Beck: *Lehre von den Erzogstatten 1*, 521 (1909), are given by Lindgren: *Mineral Deposits*, p. 543, McGraw-Hill Book Company, 1928.

In some cases, replacement may take place by a slow process of ion exchange. Such a process may be expected to occur periodically throughout the crystal, as far as atomic spacings are concerned, but in the range of the microscope would appear as a continuous encroachment on the host mineral. Possible mechanisms are illustrated in Fig. 20. In Fig. 20a it is shown that the rotation of two adjoining atoms may occur in a very small space, so that if the energy conditions are fulfilled this may be a common occurrence. The criterion is that the energy of the final state be lower than the first. As shown in Fig. 20b, bonds will be broken during the rotation and other bonds will be formed. The sum of the energy changes, energy to break bonds (positive) and energy of forming bonds (negative), must be a negative quantity. The course of such reactions will be further modified by the size of the ions and by the valence conditions. Similar ions in the same valence condition and almost the same size could be expected to show the greatest tendency to exchange. One example is the separation of sodium and potassium feldspars by the exchange of sodium and potassium ions along cleavage planes from a more or less uniform solid solution to the individual crystalline aggregates in perthite, etc. Metals form a somewhat analogous case, for interchange of ions in metals and alloys seems to be the mechanism of intermetallic diffusion. The diffusion coefficient, D, of gold in lead bars is 2×10^{-5} cm^2 day^{-1} at room temperature, only 100,000 times less than that of sodium chloride in water, and the rate of diffusion of ThB in lead foil is about the same amount at 315° C. While polonium diffused through both lead foil and crystals, no diffusion of ThB could be found when the regularly arranged structure of a single crystal of lead was used.[46a, b] Hevesy[46c] recently concluded that the coefficient of self-diffusion of lead was only 10^{-9} cm^2 day^{-1}, corresponding to a quite negligible amount of self-diffusion, and similar results were found for gold.[46d]

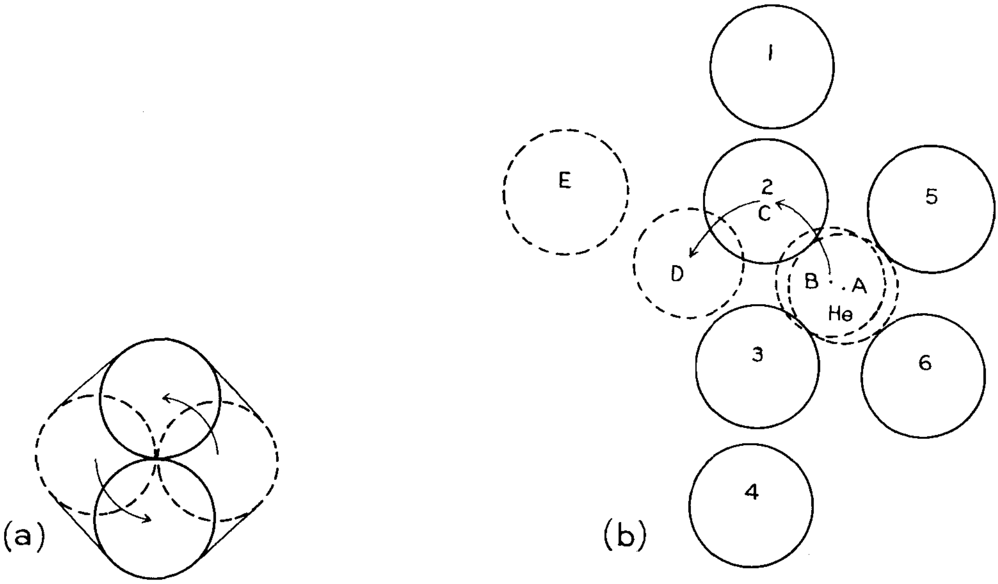

FIGURE 20. a) Shows the small space required for rotation of atoms, and the way in which it can occur with the minimum of activation energy.

b) Shows a hypothetical exchange process. Helium at A moves through position B to C while the oxygen at C moves to D. Such a process is ordinarily excluded by the energy requirements in the case of helium in minerals.

It may be argued that if self-diffusion and the diffusion of these foreign atoms can occur even to a limited extent in metallic crystals, diffusion of helium might also be possible. However, in the

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[46a] Hevesy and Groh, Ann. d. Phys. *65*, 216 (1921).

[b] Hevesy and Obrutsheva, Nature *115*, 674 (1925).

[c] Hevesy, Trans. Far. Soc. *34*, 841–845 (1938).

[d] McKay, Trans. Far. Soc. *34*, 845–849 (1938).

case of metals, where the ions are similar, diffusion can be accounted for either through the mechanism of ionic interchange as illustrated in Fig. 20 or by a loosening of the structure.* The atomic networks of metals are not so rigid as other crystals, there being more flexibility of the angles between individual ions. The binding of the atoms is due to the sea of free electrons uniformly distributed throughout the metal, and the introduction of other similar metallic ions may necessitate only slight adjustments. Helium atoms present quite a different case, for they are large compared to many metallic ions where the effective size is greatly reduced by the excess positive charges on the nuclei, and, being inert, they do not tend toward combination or exchange. That the metallic structure does not open up to permit diffusion is supported by the negative experimental results discussed later. Because of the less rigid nature of metallic structures, however, the stretching effect of helium may be larger than in silicates, so that the potential energy barriers for the diffusion of helium will be lowered, thus increasing the probabilities of diffusion during geologic time over those given in Tables VII and IX.

In Fig. 20b, the course of a hypothetical exchange of an ion in a crystal and helium is illustrated. The helium atom, A, in this two-dimensional sketch rotates simultaneously with atom 2 to take up the new position, C. In this process the resultant effect is that the bonds A–6 and 1–2 have been broken, while bonds 1–A and E–D have been formed. The latter energy must be the larger for the process to occur. This does not seem likely, since the energy of breaking 1–2, is large (the order of 100,000 cals) compared to the others. Applying this picture to the case of a quartz crystal, and neglecting for the present the question of the effect of changes in the electronic configuration, the helium atom will be surrounded by oxygen atoms in the larger spaces, and in such a shift as that in Fig. 20b, the forces between these will enter and also the interchange of oxygen bonds and the breaking of one Si–O bond. In this case the repulsive forces exerted by the atom in the free space (helium initially and oxygen finally) will enter. The energy change ΔE for the process will be given by the sum of the undirected (van der Waals) forces, and the directed cohesive forces:

$$\Delta E = \underset{\substack{\text{repul-}\\\text{sive}\\\text{forces}}}{\Delta E_r} + \underset{\substack{\text{structural}\\\text{forces}}}{\Delta E_b} \ldots\ldots\ldots\ldots (20)$$

ΔE_r will be negative if the repulsion for helium is greater than for oxygen. With a hole in the quartz structure of 1.0 Å across, the repulsive potential would be about 70,000 cals. (Table VII). The breaking of the Si–O bond requires 100,000 calories. Most of the other terms tend to cancel out, since the same types of bonds are present before and after the supposed change. The oxygen atom corresponding to 2, Figure 20b, however, will have been moved from its position of equilibrium to D, so that the energy release in forming these new O–O bonds will be less than in the formation of the original ones of the stable crystal. The resultant of these effects is to give a positive value for ΔE, which means that this energy is required for the process to occur, and therefore it will not naturally take place. This is in agreement with the prediction from the atomic sizes and the valence requirements of the problem. It should be noted that the over-all repulsion in smaller holes will be larger and may be of the same order of magnitude as the energy required to break an Si–O bond, and there may be some shifting of helium from smaller spaces in the crystal structure to larger ones. It seems plausible, though, that the helium initially comes to equilibrium in a larger spacing, possibly in that provided by the rearrangement at the time of bombardment by the alpha particle.

Attempts to Force Helium through Minerals

All direct attempts to pass helium through crystals have failed. Urry[38] found no helium to diffuse through quartz, iron, or bismuth; Piutti and Bozzio-Lera[47] obtained negative results with quartz; while Rayleigh[48] could find no trace of helium diffusing through calcite, quartz, mica, halite, selenite, fluorite, or beryl, or through various metals: magnesium, aluminum, zinc, or copper. Even increasing the temperature to 415° C. for twenty-four hours did not make permeable a mica disc 4.5 cm. in diameter and 0.2 mm. in thickness. While the limit of detection of helium was not very great, the results provide an upper limit and at least show that less than one in 10^{19} atoms of helium colliding with the crystal can get through.

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* Bernal, in a recent note [Trans. Far. Soc. *34*, 849–850 (1938)], considers that the high activation energies found for intermetallic diffusion support the theory of diffusion through holes since the energy approaches that necessary to break a bond, for example, in interionic rotation. The neighboring atoms are pictured as always tending to fill a hole, and in so doing producing dislocation. Wagner (ibid, pp. 851–859) considers that diffusion in metals and in some ionic compounds may be interpreted by the movement either of the interstitial atoms or of the holes, which are in thermodynamical equilibrium with the whole crystal, and does not favor the theory of ionic exchange. Experimental results on the electrical conductivity of various substances are given in support of his theory. The addition of $CaCl_2$ to $AgCl$ caused crystal imperfections (to the extent that 10^{-4} to 10^{-5} of the crystal is thought to be made up of holes), and an increased electrical conductivity resulted.

The results of the experiments with helium and various crystals are summarized in the first three columns of Table XII; these have been recalculated to give an upper limit to the number of atoms diffusing per second through one square centimeter of surface and a thickness of one millimeter. From kinetic theory, the maximum fraction of atoms passing through can be obtained (Table V; column 4). From this, and an assumption regarding the reflection coefficient, lower limits for the activation energy have been calculated, and are given in the last column.

From the results in Table IX, it can be calculated that the effective heights of the barriers giving the upper limits of diffusion are about 49,500 at 300° K. and 46,500 at 600° K. The data summarized in Table XII, then, provide an experimental check on the limits of diffusion. Thus, for mica the experimental value shows that E is greater than 47,000, and no self-diffusion would be expected.* The limits of detection for quartz need to be extended, but they at least show that E is greater than 23,000 cals.

On the basis of both the experimental and the theoretical results, the conclusion would be that there can be no diffusion of helium atoms through most perfect crystals. A few which might be exceptional are those in which large channels are present in the atomic network. In beryl, these are 2.6 Å wide, and although helium might be expected to diffuse easily through this mineral, it is important to note that none could be detected by Rayleigh in several attempts, and that the natural helium content of this mineral is often excessively high. These results suggest that the

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[47] Piutti and Bozzio-Lera, R. C. Accad. Napoli *29*, 111 (1923).

[48] Rayleigh, Proc. Roy. Soc. London *A156*, 350 (1936); *A163*, 376 (1937).

* Apparently the direction of attempted diffusion was perpendicular to the cleavage.

TABLE XII

SOME CONCLUSIONS FROM EXPERIMENTAL ATTEMPTS TO FORCE HELIUM THROUGH CRYSTALS

Crystal	Upper limit for diffusion of helium; cu. mm. per sec. through 1 sq. cm. surface and 1 mm. thickness	No. of atoms diffusing through per second	Max. fraction, F, of atoms impinging on surface which can pass through	Activation energy,* Kcal.
Quartz,[1] perpendicular to optic axis	1.5×10^{-10}	$<4 \times 10^{6}$	4×10^{-18}	>21.5
Mica[1]	1.7×10^{-11}	$<4.5 \times 10^{5}$	4.5×10^{-19}	>22.5
Calcite[1] (cleavage plate)	1.3×10^{-10}	$<3.5 \times 10^{6}$	3.5×10^{-18}	>21.5
Rock salt[1]	5.7×10^{-8}	$<1.5 \times 10^{9}$	1.5×10^{-15}	>18.0
Beryl,[1] cut perpendicular to axis	3.1×10^{-10}	$<8.3 \times 10^{6}$	8.3×10^{-18}	>21.0
Beryl,[1] cut parallel to axis	4.3×10^{-9}	$<1.1 \times 10^{8}$	1.1×10^{-16}	>19.5
Selenite[1]	1.8×10^{-11}	$<4.8 \times 10^{5}$	4.8×10^{-19}	>22.5
Fluorite[1]	5.9×10^{-10}	$<1.3 \times 10^{7}$	1.3×10^{-17}	>20.5
Quartz, bismuth, and iron[2]	10^{-15}	$<2 \times 10^{4}$	2×10^{-20}	>24.5
Mica[3]	8.1×10^{-10}†	$<2.2 \times 10^{7}$	1.5×10^{-17}	>47.0

[1] Rayleigh, Proc. Roy. Soc. London *A156*, 350 (1936).

[2] Urry, J. A. C. S. *54*, 3887 (1932); *55*, 3242 (1933).

[3] Rayleigh, Proc. Roy. Soc. London *A163*, 376 (1937).

* Taking $e^{-E/RT} = \frac{F}{\kappa}$, where F is given by column 4, and κ is a factor which corrects for the fact that only a fraction of the surface is covered with "holes," and that those atoms in the gas striking the surface at a sharp angle will not get through. κ is assumed to be 10^2.

† 415° C.

effective diameter of helium within minerals is greater than 1.9 Å, and provide further evidence of the retention of helium by minerals.

Accelerated Tests on Diffusion

Most of the earlier experiments were performed with helium at one atmosphere pressure, and an evacuated collecting vessel. It would be preferable to use a higher concentration gradient by increasing the pressure on the high pressure side to a few thousand atmospheres, using the highest temperatures and the thinnest plates feasible. At one thousand atmospheres, for instance, the rate would be increased one thousand-fold assuming that, as with silica glass, the relation of diffusion to pressure is linear. Then by increasing the temperature, the upper limit for diffusion could easily be determined to better than 10^6 atoms or 4×10^{-11} cu. mm. per second through one sq. cm. and one mm. thickness, which would be quite satisfactory for determining the limit for the activation energy required for the problem of self-diffusion. With a pressure of one thousand atmospheres, the diffusion of helium through silica glass would be 10^{17} atoms per second through one square centimeter of surface and one millimeter of thickness at 600° K. (Table V), with an activation energy of 5500 calories, so that

$$N = 10^{17} = kN_0e^{-5500/1200} \quad \ldots\ldots(11)$$

where N_0 is the total number of collisions with one square centimeter of surface (Equation 10), and k is the fraction of activated atoms getting through. The average size of the holes in silica glass is taken as about 2.3 Å. Table XIII gives the approximate number to be expected through crystals with smaller holes.

The maximum probabilities of crossing at 600° K. given in the third column were taken from Table IX. The ratio of the number of atoms diffusing through a crystal to the number through the *pores* in silica glass at 600° K. is given by

$$\frac{N}{10^{17}} = \frac{k_1N_0e^{-E_1/RT}}{k_2N_0e^{-5500/1200}},$$

where $\frac{k_1}{k_2}$ is the ratio of the transmission coefficients for a crystal and glass respectively, and is assumed from the data given in Table VI to be 10^{15}. The results indicate that the approximate limit of detection would be the distance between the cleavage sheets in feldspars and micas, or possibly the width of channels parallel to the c-axis in quartz, but since we have chosen values that would give the maximum rate, it is doubtful whether any diffusion could occur in perfect crystals of these minerals. Diffusion under a high pressure gradient should take place readily through beryl[5e] (hole of 2.6 Å) and valentinite,[49] but not through most of the common minerals. The difficulty with such diffusion experiments is in the interpretation of the results. A few slight imperfections in the crystal structure, while negligible in helium age work, would make the diffusion data meaningless as far as determining the hole size and energy barriers within crystals is concerned, because all of the diffusion may take place through imperfection channels. It is doubtful whether any crystals are perfect in structure.

TABLE XIII

APPROXIMATE RATES OF DIFFUSION AT p = 1000 ATMOSPHERES

R (He–O), Å	Diameter of hole, Å	Probability of crossing barrier, T = 600° K.	N, diffusion, atoms per second
1.6	0.6	10^{-43}	10^{-11}
1.7	0.8	10^{-30}	10^{2}
1.8	1.0	10^{-17}	10^{15}
1.9	1.2	10^{-10}	10^{22}
2.0	1.4	10^{-6}	10^{26}
2.1	1.6	$10^{-2.5}$	10^{30}

The Effects of Metamorphism

Any environment which changes the arrangement of the atomic network or causes chemical alteration in rock minerals will have an effect on helium retention. Changes which cause shearing and crystal rearrangement will open more channels for the escape of helium, but these would have to be fairly extensive before the effect would be appreciable. It appears on the surface that thermal metamorphism would be more serious, for experiments have shown some loss of helium at temperatures over 400° C. Complete melting and recrystallization would remove the helium, and an age determination on such a metamorphic rock would give the time since metamorphism. In most cases, not all of the helium would have escaped, and an age determination would give a result somewhere between the time of original consolidation and the time of metamorphism. The effects of metamorphism can be estimated by direct determinations of the helium age, and by combining experiments on helium liberation at different temperatures with experiments on thermal expansion and compressibilities.

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[49] Buerger, private communication.

Age determinations on schists and gneisses have given "low" results, but a large range of other rocks which have experienced many geological cycles and moderate changes in environment have yielded age results in agreement with the usual geological succession. It is significant that an early Precambrian rock from the Stillwater series, near Yellowstone Park, was recently found to give a helium age of nearly two billion years, as high as any age previously determined by either the helium or the lead method. Although there were no visible effects of metamorphism, it is significant that such a high age value could be obtained for a rock that has experienced all the changes from early Precambrian times to the present.

The low helium content of the atmosphere suggests that the helium may not be expelled completely during metamorphism or weathering processes. Helium forms about 0.00053 per cent of the volume of the atmosphere, and can be accounted for by the erosion of forty metres of rock from the earth's surface;[50] whereas the amount of erosion in geological time is of the order of miles. Some helium is present in the ocean; the amount is not known accurately, but it appears to be less than that in the atmosphere. The proportion in the atmosphere does not change noticeably up to a height of about twenty miles. A slight increase was observed by Paneth,[51] but the samples were taken in the zone of turbulent mixing, so are not of much significance. Other than this result, there is yet no indication of helium at higher levels, and no spectral lines of it have been found.[52] It is possible, though, that the rate of escape of helium from the atmosphere may be equal to its rate of escape from the ground. The mechanism would have to be the acquiring of sufficient energy by collision with other excited atoms to impart a velocity great enough to exceed the velocity of escape. It has been calculated that collisions with oxygen in the ^1s state would increase the agitation of hydrogen and helium above the critical velocity.[53]

Since some helium is liberated slowly from rocks at temperatures above 300° and 400° C., it might be expected that considerable loss would have occurred in the geological history of almost any rock. Such an inference cannot be made, however, because the conditions in the laboratory experiments have been much different from those within the crust of the earth. In the laboratory, specimens were ground and heated in evacuated furnaces, whereas in the earth the rocks have been in the massive state and under high pressures. If we analyze the individual conditions of these two processes, we find that in the first, the rock is allowed to expand freely with the temperature, the helium atoms acquire more thermal energy, and the amplitudes of vibration are increased, thus providing larger holes in the crystal for diffusion, while in the other the effect of pressure is in the opposite direction and tends to lessen the free space within and between crystals.

It is found that in solid rocks under pressure the expanding effect of temperature is about compensated by the compressing effect of pressure. The volumetric thermal expansion (fractional volume change) of granite is about 40×10^{-6}, for basaltic material about 25×10^{-6} per degree. Taking the temperature gradient in the earth's crust as 20° C. per kilometer, the thermal expansions are 8×10^{-4} and 5×10^{-4} respectively. The coefficients of compressibility (fractional volume change per sq. cm. per kg.) are about 20×10^{-7} for granites and 12×10^{-7} kg. per cm.^{2} for basaltic type rocks. The change per kilometer for granite would be $2.7 \times 100 \times 20 \times 10^{-7} = 5.4 \times 10^{-4}$; for basalts, $3.0 \times 100 \times 12 \times 10^{-7} = 3.6 \times 10^{-4}$. These results cannot be compared quantitatively because of our limited knowledge of the temperature gradient, but they at least indicate that the effects of temperature and pressure counterbalance each other at moderate depths. The previous remarks on radioactive minerals suggest that pressure is the more important. Loss of helium may then be expected to occur only in those rocks in which the crystal structures have been changed, either by excessive shearing and strain, or by alteration through weathering or in deep-seated melting and recrystallization. The presence of such metamorphic changes can be detected by petrographic examination.

SUMMARY

A review of the literature on the dimensions of the helium atom, and construction of potential

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[50] Jeffreys, The Earth, Macmillan Company, New York, p. 313 (1931).

[51] Paneth, F., Nature *136*, p. 717 (1935); Nature *138*, p. 834 (1936).

[52] Gutenberg, Private communication.

[53] Russel and Menzel, Proc. Nat. Acad. Sci. *19*, 997–1001 (1933).

energy curves involving helium, have shown that the size is large compared to the structural "holes" in common minerals. The value obtained for the size is substantiated empirically by interpolation of the curve relating radius and charge of ions possessing the helium shell of electrons.

While the results indicate that diffusion is not possible through perfect, solid, close-packed atomic models, the application to the helium age problem requires an estimate of the effect of several other factors which might permit some diffusion of helium through rocks during the vast extent of geological time.

On the basis of results of petrographic studies of the distribution of radioactivity in rocks, it is assumed that most of the helium in the individual minerals is not localized to any great extent. The problem then resolves into finding the probability of the helium atom's migrating through the crystal once it has formed.

It seems plausible that the immediate environment in the crystal becomes adjusted to some new equilibrium condition after the alpha particle has acquired its electrons, leaving the helium atom surrounded by high potential energy barriers. Its chance of escaping through distortion channels resulting from radioactive decay would be high in radioactive minerals, but in ordinary rock minerals would be small except for rare local concentrations occurring along lineage or cleavage planes, or at crystal surfaces. The calculations indicate that an opening 1.2 Å wide would have to be formed before escape was possible through a channel.

Calculations based upon an activation energy treatment have provided estimates of the mean distance of diffusion of helium atoms through crystalline structures during geological time. It is assumed that to move from one of the positions of minimum potential energy within a crystalline network, the atom must acquire an energy equal to or greater than a certain critical value. The heights of such barriers have been estimated from the interatomic energy calculations and the experimental data on the permeabilities of helium in glasses. The results indicate that no diffusion can occur when the interatomic distances (helium to oxygen) are less than 1.9 Å. On this basis, diffusion of helium would be expected to occur in beryl and valentinite, but not through the regular atomic frameworks of common rock minerals. Owing to the dependence of the energy of interaction on the distance of separation, if diffusion were possible through crystal spacings the effect would be so extensive during geological time that a uniform concentration of helium throughout the rock would be attained. This condition is contradicted by helium age measurements.

The problem of helium retention in ordinary rocks is discussed on the basis of present knowledge. A consideration of several factors indicates that the migration of helium would ordinarily be expected to be less than eight per cent. The loss from crystal growth imperfections and through the interstices in rocks is probably about three-tenths per cent, judging from compressibility data, but porosity determinations and calculations on the maximum volume of lineage sheets indicate a maximum of three per cent. The effects of radioactive decay on surface loss from crystals appear to be less than five per cent (except in very fine-grained rocks). Although several factors have been shown to be negligible, other conditions may cause excessive losses, and should be guarded against in helium age work. With a high degree of imperfection resulting from strains during growth, inclusions, or alterations of the mineral, greater losses may be expected. Also, any excessive local concentrations of radioactivity might cause rupture, especially along cleavage planes, thus permitting escape. Helium may be expelled completely during recrystallization, but mild thermal metamorphism would appear to have no effect.

While helium ages of rocks are usually considered as minima, the factors considered in this paper indicate that ages obtained on carefully selected minerals should not differ from the true values by more than the present experimental errors of measurement. This preliminary treatment is admittedly limited, but it is hoped that some of the questions which have arisen since the first application of the helium method have been answered in part, and that it will stimulate further theoretical treatments, and aid in directing the course of much-needed experimentation.

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SOME PHYSICAL CONSTANTS OF A FEW HYDROCARBONS AND THEIR STRUCTURAL ISOMERS[1]

By Mieczyslaw Wojciechowski[2]

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1. Introduction

In previous papers it has been shown that in the homologous series of normal saturated hydrocarbons [22],[3] normal aliphatic alcohols [23], and acetates of normal aliphatic alcohols [24], when containing more than some small number, n, of carbon atoms (in the case of acetates beginning with the first member) the addition of a CH_2 group to the normal alkyl group to form the next higher normal alkyl group results in an increase of approximately 0.0029° C. per mm. of mercury in the coefficient dt/dp at the normal boiling point. Since this value was found to be independent of the chemical nature of the compound, the additivity of the effect of the CH_2 group on dt/dp was postulated. However, n-nonane, which has a boiling point of 150.81° C. and a dt/dp of 0.0497° C. per mm. of mercury, has been found to deviate somewhat from this rule. It is, then, important to examine isomeric compounds for further tests of the postulate.

This paper describes measurements of dt/dp coefficients of five isomeric hexanes: n-hexane, 2-methylpentane, 3-methylpentane, 2, 3-dimethylbutane, and 2, 2-dimethylbutane; of six isomeric heptanes: n-heptane, 2, 3-dimethylpentane, 2, 2-dimethylpentane, 3-ethylpentane, 3-methylhexane, and 2, 2, 3-trimethylbutane; of two isomeric octanes: n-octane and 2, 2, 4-trimethylpentane; of two isomeric nonanes: n-nonane and 2, 5-dimethylheptane; and of the three isomeric xylenes. In addition, there are included for comparison the results of previous measurements on the isomeric nonanes: 2-methyloctane, 3-methyloctane, 4-methyloctane and 2, 6-dimethylheptane. There are also reported the boiling points of these compounds and the freezing points of the isomeric hexanes.

2. Methods of Measurements

For determining boiling points, W. Swietoslawski's ebulliometric technic [15], a comparative method with water as a primary reference standard, was used. Details of the experimental procedure for measurements of boiling point and dt/dp have been reported briefly in former papers [22, 2].

For calculating the normal boiling point, the formula [22]

$$t_s = t_s' + \frac{\Delta t_s}{\Delta t_w}(100 - t_w') \qquad (1)$$

was used. In this equation t_s represents the normal boiling point of the substance under investigation, t_s' the boiling point of water actually measured under the same pressure as that of the substance. The ratio, $\Delta t_s/\Delta t_w$, of the change in boiling point of the substance to the change in boiling point of water at normal pressure was computed from the boiling point of the substance under investigation and that of water under the same pressure, slightly above and slightly below 1 atm.

By a method which has been described previously [22, 25], the boiling points measured were corrected whenever possible by extrapolation, to minimize the effect of impurities in the preparations investigated.

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[1] Publication approved by the Director of the National Bureau of Standards of the Department of Commerce.

[2] Guest worker at the National Bureau of Standards from the Polytechnic Institute, Warsaw, Poland.

[3] Numbers in brackets throughout the text indicate references listed at the end of the paper.

All temperature measurements were made with a platinum resistance thermometer and Mueller bridge, calibrated at this Bureau.

3. Materials Used

The isomeric hexanes used were synthetic materials kindly furnished by L. Cramer and M. J. Mulligan [6] of the General Motors Corporation. Each of the substances investigated was examined for purity in a Swietoslawski standard differential ebulliometer [15]. The ebulliometric test, which is based on measuring the difference Δt between the boiling point and temperature of condensation of the substance, indicated high purity, all of the hexanes being of the fifth or of the fourth degree of purity on Swietoslawski's scale.

Isomeric heptanes were obtained from G. Calingaert of the Ethyl Gasoline Corporation. These preparations, although not of the highest purity, were satisfactory for measurements of dt/dp, since these constants are not very sensitive to small quantities of impurities. The sample of 2, 2-dimethylpentane, kindly furnished by F. W. Rose, Jr., of the American Petroleum Institute Research Project 6 at this Bureau, was a preparation of the fifth, i. e. the highest degree of purity.

The *n*-nonane was obtained from S. T. Schicktanz and the isomeric xylenes from J. D. White and F. W. Rose, Jr., research associates of the American Petroleum Institute. The values given for 2, 2, 4-trimethylpentane are those reported recently by E. R. Smith and H. Matheson [14].

4. Experimental Results and Conclusions

(a) *Isomeric hexanes.*—The data obtained for the isomeric hexanes are given in Table 1, which shows for each substance the difference, Δt, between boiling point and condensation temperature, the normal boiling point, the value of dt_s/dt_w (the ratio of the change of boiling point of each substance to the change of the boiling point of water, caused by a small increase or decrease of pressure, obtained directly in these comparative measurements), and the value of dt/dp (the increment of boiling point of the substance under investigation per millimeter change of pressure at 1 atm.). The value for *n*-hexane was calculated from the dt_s/dt_w ratio given in a former paper [22], taking the value 0.036858° C. per mm. of mercury for the dt/dp coefficient of water reported by Beattie and Blaisdell [1]. This figure was used for computing the dt/dp coefficients of all the hydrocarbons investigated.

The data for dt_s/dt_w permit the calculation of the correction for normal boiling points of the substances from equation 1, within the pressures expressed by the boiling points reported for water, or even when extrapolated for somewhat larger pressure differences. In the latter case, the accuracy of the results decreases with increase in magnitude of the pressure difference.

The data for dt_s/dt_w may also be used to compute the value of the dt/dp coefficient corresponding to any pressure within the reported limits by the use of the equation [15]

$$\left(\frac{dt}{dp}\right)_s = \frac{dt_s}{dt_w}\left(\frac{dt}{dp}\right)_w$$

The purity of the isomeric hexanes used was confirmed by examining the freezing curves, using an apparatus similar to that of Mair [11].

The freezing curve of the 2-methylpentane was practically flat. A rise in the freezing curve was observed at the first stage of freezing, when the liquid was seeded, and a slight decrease was noticed at the end of the measurement, when the mixture of liquid with crystals was so viscous that stirring of the material was almost impossible. Obviously, the heat exchange under the conditions at the end of the measurement was not adequate to maintain thermal equilibrium in the system. The shape of the freezing curve indicated high purity of the substance. More than two-thirds of the sample crystallized at constant temperature within ± 0.003° C. This is in agreement with the ebulliometric test of purity. Indeed the discrepancy between the boiling point and the condensation temperature for the given sample of 2-methylpentane was found to be only 0.002° C., which also classifies the preparation as very pure.

The flatness of a freezing curve proves that in the substance investigated there are only slight amounts of impurities which might be removed by fractional crystallization. The small difference between the boiling point and condensation temperature, as measured in the differential ebulliometer, shows that there are but slight amounts of impurities that might be removed by distillation. Since there is only a very smal probability that there can be impurities presen having both boiling and freezing points almos equal to those of the substances investigated, th claim of high purity for 2-methylpentane is sub

TABLE 1

DATA FOR ISOMERIC HEXANES

Substance	Δt	Normal boiling point	dt_s/dt_w	Boiling point of water	$(dt/dp)_{760}$
	° C	° C		° C	° C/mm
2-Methylpentane	0.002	60.26_7	1.1261	100.888	0.0414
			1.1236	100.000	
			1.1182	98.022	
3-Methylpentane	.005	63.25_6	1.1374	100.961	.0418
			1.1354	100.000	
			1.1319	98.334	
2, 3-Dimethylbutane	.004	58.02_2	1.1346	101.091	.0417
			1.1311	100.000	
			1.1286	98.428	
2, 2-Dimethylbutane	.009	49.80_4	1.1188	101.137	.0411
			1.1163	100.000	
			1.1129	98.503	
n-Hexane	.005	68.73_3	1.1383	101.075	.0419
			1.1363	100.000	
			1.1324	97.948	
				Average	0.0416

TABLE 2

COMPARISON OF DATA FOR ISOMERIC HEXANES

Substance	Author	Normal Boiling point	Freezing point	$(dt/dp)_{760}$
		° C	° C	° C/mm
2-Methylpentane	Chavanne [5]	60.2	—	—
	Maman [12]	60.5	—	—
	Bruun and Hicks-Bruun [4]	60.4	-143 ± 0.5	—
	Edgar and Calingaert [8]	60.2	—	—
	Cramer and Mulligan [6]	60.22 to 60.26	—	—
	Wojciechowski	60.26_7	-153.7_1	0.0414
3-Methylpentane	Chavanne [5]	63.2	—	—
	Maman [12]	62.7	—	—
	Bruun and Hicks-Bruun [4]	63.3	-118 ± 0.5	—
	Edgar and Calingaert [8]	63.2	—	—
	Cramer and Mulligan [6]	63.16 to 63.21	—	—
	Wojciechowski	63.25_6	—	0.0418
2, 2-Dimethylbutane	Chavanne [5]	49.7	—	—
	Maman [12]	52.9	—	—
	Cramer and Mulligan [6]	49.80 to 49.82	—	—
	Wojciechowski	49.80_4	-102	.0411
2, 3-Dimethylbutane	Chavanne [5]	58.1	—	—
	Maman [12]	58.2	—	—
	Bruun and Hicks-Bruun [4]	58.0	-135 ± 1	—
	Edgar and Calingaert [8]	58.1	—	—
	Cramer and Mulligan [6]	57.82 to 58.02	—	—
	Wojciechowski	58.02_2	-132.7	.0417

stantiated, and the value -153.7_1° C. for its freezing point seems reliable.

The freezing point of 3-methylpentane could not be measured because the substance supercooled without crystallization and became so viscous that stirring was impossible. All attempts failed to cause crystallization by seeding or by local extreme supercooling.

2, 3-Dimethylbutane and 2, 2-dimethylbutane were also very difficult to crystallize by seeding. For this reason the freezing points of these two compounds, -132.7 ± 1° C. and -102.0 ± 1° C., respectively, can not be reported with better accuracy than 1° C.

Taking into consideration the high purity of the substances, with the exception of 2, 2-dimethylbutane, it is believed that the data obtained for the boiling points can hardly differ by more than 0.01° from the true boiling points of these compounds. The values for dt/dp can be affected only very slightly by the presence of small amounts of impurities, and it is possible that the data for 2, 2-dimethylbutane alone might be significantly in error for this reason.

The data contained in Table 1 show that the values of the coefficient dt/dp for all the hexanes fluctuate, probably because of the rearrangements in the chain, within about 1 per cent of the average value of 0.0416° C/mm.

In Table 2 the author's data for isomeric hexanes are compared with values previously reported.

(b) *Isomeric heptanes.*—The data for the five isomeric heptanes are reported in Table 3, where the headings are self-explanatory.

The boiling points contained in Table 3 are the actual data of measurements carried out within a precision of 0.001° C. However, the accuracy of the data is much lower on account of the considerable amount of impurities in the preparations. The impurities caused relatively large values of Δt, the difference between the boiling point and the temperature of condensation, as for instance 0.127° C. in the case of 2, 3-dimethylpentane. Hence the boiling points may differ from the true values for the investigated compounds by several hundredths of a degree or even more. The only exception is 2, 2-dimethyl-

TABLE 3

DATA FOR ISOMERIC HEPTANES

Substance	Δt	Normal boiling point	dt_s/dt_w	Boiling point of water	$(dt/dp)_{760}$
	° C	° C		° C	° C/mm
2, 2-Dimethylpentane	0.002	79.21_0	1.1951 1.1920 1.1875	100.759 100.000 97.755	0.0439
2, 3-Dimethylpentane	.127	89.94_2	1.2198 1.2170 1.2130	100.670 100.000 97.972	.0449
3-Ethylpentane	.040	93.36_8	1.2179 1.2156 1.2123	100.726 100.000 97.884	.0448
3-Methylhexane	.029	91.87_9	1.2105 1.2078 1.2040	100.746 100.000 97.838	.0445
2, 2, 3-Trimethylbutane	.090	80.96_1	1.2174 1.2154 1.2126	101.041 100.000 97.948	.0448
n-Heptane [14]	.001	98.41_3	1.2179 1.2168 1.2128	101.034 100.000 98.018	.0448
				Average	0.0446

TABLE 4

COMPARISON OF DATA FOR ISOHEPTANES

Substance	Author	Normal boiling point	$(dt/dp)_{760}$
		° C	° C/mm
2, 2-Dimethylpentane	Edgar and Calingaert [8]	78.9	—
	Wojciechowski	79.21_0	0.0439
	Brooks, Cleaton and Carter [3]	79.23	.0445
2, 3-Dimethylpentane	Edgar and Calingaert [8]	89.7	—
	Wojciechowski	89.9	.0449
3- Ethylpentane	Edgar and Calingaert [8]	93.3	—
	Wojciechowski	93.3_7	.0448
3-Methylhexane	Edgar and Calingaert [8]	91.8	—
	Wojciechowski	91.8_8	.0445
2, 2, 3-Trimethylbutane	Edgar and Calingaert [8]	80.9	—
	Wojciechowski	80.9_6	.0448

TABLE 5

BOILING POINT AND dt/dp COEFFICIENT DATA FOR 2, 2, 4-TRIMETHYLPENTANE AND n-OCTANE

Substance	Δt	Boiling point	dt_s/dt_w	Boiling point of water	dt/dp
	° C	° C		° C	° C/mm
2, 2, 4-Trimethylpentane [14]	0.001	99.23_4	1.2619	100.000	0.0465
n-Octane [22]	.008	125.65_8	1.2887	100.000	.0475

pentane whose Δt of 0.002° C. indicated its high degree of purity The value measured for its boiling point, 79.210° C., can differ by not more than a few thousandths of a degree from the true boiling point of 2, 2-dimethylpentane. F. W. Rose, Jr., kindly supplied a second preparation having a Δt of 0.003° C. and a boiling point of 79.208° C. The agreement of the data for the two also indicates the high purity of the preparations.

It is most probable that the preparations contain hydrocarbons isomeric with the main substance as impurities. In such a case the impurities may affect appreciably the boiling points, but can have only a very small influence on the dt_s/dt_w ratios and hence on the dt/dp coefficients. It is obvious that the preparations were good enough for precise measurements of the latter constants.

The results tabulated in Table 3 show that in the case of isoheptanes, as in the case of isohexanes, the coefficient dt/dp exhibits only small variations from the average value of 0.0446° C/mm. The difference between the average coefficients for the hexanes and heptanes, however, is 0.0030° C/mm, an amount which is characteristic in comparison with the differences within the separate sets of isomers.

In Table 4 there are compared the author's data with those obtained by others.

(c) *Isomeric octanes.*—The results of measurements of the boiling points and dt/dp coefficients for n-octane and for 2, 2, 4-trimethylpentane have been reported in previous papers [22, 14]. Some data for them at their normal boiling points are given for reference in table 5. In this case the difference between the coefficients, dt/dp, for the octanes and heptanes is 0.0024° C/mm, which is again distinctive in comparison with the variations within each group.

(d) *Isomeric nonanes.*—Measurements of boiling points and dt/dp coefficients of n-nonane and 2, 5-dimethylheptane were made. There were used two samples of n-nonane of different purities, which permitted the calculation of the

TABLE 6

DATA FOR ISOMERIC NONANES

Substance	Δt	Normal boiling point	dt_s/dt_w	Boiling point of water	$(dt/dp)_{760}$
	° C	° C		° C	° C/mm
n-Nonane	0.016	150.81[a]	1.3515 1.3498 1.3460	100.924 100.000 97.902	0.0497
2, 5-Dimethylheptane	.033	135.208	1.3276 1.3265 1.3238	100.623 100.000 98.445	.0489
2, 6-Dimethylheptane	.024	135.21	1.329	100.000	.0490
2-Methyloctane	.044	143.26	1.342	100.000	.0495
3-Methyloctane	.028	144.18	1.346	100.000	.0496
4-Methyloctane	.013	142.49	1.334	100.000	.0492
				Average	0.0493

[a] Extrapolated value.

boiling point of pure *n*-nonane by extrapolation. The 2, 5-dimethylheptane was supplied by J. D. White, who has reported its boiling point [21].

The data for the isomeric nonanes are given in table 6. The values for 2, 6-dimethylheptane, 2-methyloctane, 3-methyloctane and 4-methyloctane are those obtained by E. R. Smith.[4]

Although the preparations of *n*-nonane were not of the highest purity, since their purities might be classified on Swietoslawski's scale by the fourth and third degrees, it was possible to extrapolate the boiling point in the way formerly reported [25]. The value of 150.81° C. thus obtained for the boiling point of *n*-nonane is uncertain in the second decimal place. This value differs considerably from that of 150.6° C. reported by Edgar and Calingaert [8]. The uncertainty in the boiling point of 2, 5-dimethylheptane, 135.21°, is probably a few hundredths of a degree. The dt/dp coefficients are probably slightly affected by impurities, but not so much as to cause the difference of 0.0008 between the values of this constant for both isononanes investigated. This difference is probably due to some constitutional influence. Nevertheless, an approximately characteristic value of the dt/dp coefficient, as in the series of isomeric hexanes, heptanes and octanes, is again observed, the difference of 0.0023° C/mm between the average values for the nonanes and octanes being characteristic in comparison with the individual variations. The difference between the smallest value, 0.0489, for the nonanes and the larger value, 0.0475, for the two octanes is 0.0014, which is sufficiently greater than differences within each set to be distinctive.

(e) *Isomeric xylenes.*—Measurements were made of boiling points and dt/dp coefficients of the three isomeric xylenes. The preparation and purification of these compounds have been described by J. D. White and F. W. Rose, Jr. [20] The substances used in the present work were of the fourth and the third degree of purity. The data obtained for the boiling points were corrected for the influence of impurities.

Table 7 contains the data for the thre xylenes.

Since the boiling points have been extrapolate to minimize the effect of impurities in the prepa rations, it is believed that the boiling points re ported do not differ by more than one or tw hundredths of a degree from the true boilin points of these xylenes. The boiling point o *m*-xylene is considered especially reliable sinc the preparation used for measurements was c the fourth degree of purity. The coefficient dt/d in the case of the xylenes has a fairly characteri tic value. The data for *m*- and *p*-xylene are th same and equal to 0.0491, while that for *o*-xyle is somewhat higher. It may be worth noting th the average value for the xylenes, 0.0493, greater than that for toluene, 0.0463, by abo the same amount as appears to be more or le characteristic of the difference between adjace sets of aliphatic isomers..

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[4] The data are reported in a paper by J. D. White and A. R. Glasgow, Jr. [19].

TABLE 7

DATA FOR dt_s/dt_w AND dt/dp OF THE XYLENES

Substance	Δt	Boiling point	Boiling point corrected	dt_s/dt_w	Boiling point of water	$(dt/dp)_{760}$
	° C	° C	° C		° C	° C/mm
o-Xylene	0.034	144.466	144.5_0	1.3510	101.001	0.0497
				1.3499	100.000	
				1.3483	98.503	
m-Xylene...........	.009	139.091	139.1_0	1.3344	100.633	.0491
				1.3331	100.000	
				1.3304	98.821	
				1.3267	96.757	
p-Xylene............	.036	138.402	138.4_4	1.3349	101.979	.0491
				1.3328	100.806	
				1.3316	100.000	
				1.3297	98.793	
					Average	0.0493

TABLE 8

COMPARISON OF DATA FOR THE XYLENES

Observer	*o*-Xylene		*m*-Xylene		*p*-Xylene	
	Normal boiling point	$(dt/dp)_{760}$	Boiling point	$(dt/dp)_{760}$	Normal boiling point	$(dt/dp)_{760}$
	° C	° C/mm	° C	° C/mm	° C	° C/mm
Mathews [13]	142.6 to 142.8		139.3 to 139.4		138.4	
Int. Crit. Tables [10]	144					
Huffman, Parks and Daniels [9]	144.5		139.0			
White and Rose [20]	144.4		139.15		138.4	
Timmermans and Martin [17]					138.40	0.041 to 0.042
Timmermans and Henaut-Roland [16]			139.30	0.049		
Wojciechowski	144.50	0.0497	139.10	.0491	138.44	0.0491

Table 8 contains a comparison of the author's data with some reported in the literature.

In Table 9 are tabulated the values for boiling points and dt/dp coefficients discussed in this paper.

An analysis of the dt/dp coefficients in the series of isomeric hydrocarbons, as listed in Table 9, leads to the conclusion that the rearrangement of a molecule results in variations of the value of the coefficient, dt/dp, which are minor in comparison with the rather characteristic difference observed between one group and the next higher group. Small deviations from the values obtained for corresponding normal compounds are probably caused by constitutional influences. This conclusion is true also in the case of the three xylenes, which are representative of the aromatic hydrocarbons.

The results of this work confirm further the approximate additivity of the coefficient dt/dp, postulated in previous publications [22, 23]. From these results further consequences can be derived. It is well known that Trouton's rule [18] is not generally valid. The discrepancies for different compounds are so large that it is difficult to claim constancy of the ratio, L_m/T, of the molar latent heat of vaporization to the absolute temperature, even as a first approximation. The results here reported show that this ratio has a nearly constant value in the case of structural isomers. Indeed, in the equation

$$\frac{L_m}{T} = \frac{V_v - V_l}{dt/dp}$$

the right-hand member has the same value for isomeric compounds, since the value of their *dt/dp* coefficients is so nearly the same, and the molar volume of vapor and that of liquids are also very nearly the same for all isomers. Hence it may be postulated that the entropy of vaporization of structural isomers has a substantially constant value.

5. SUMMARY

Normal boiling points and rates of change of boiling point with pressure of isomeric hexanes, heptanes, octanes, nonanes, and xylenes, and the freezing points of some isomeric hexanes were determined. The data are discussed and tabulated with values from other investigations.

The data confirm the rule postulated in a previous paper that the coefficient *dt/dp* is approximately an additive property, and show that the rearrangement of a molecule does not greatly affect the magnitude of the *dt/dp* coefficient. From this latter fact, the entropies of vaporization of structural isomers have substantially the same value.

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TABLE 9

SUMMARY OF BOILING POINTS AND *dt/dp* COEFFICIENT

Substance	Normal Boiling point	$(dt/dp)_{760}$
	° C	° C/mm
	Isomeric hexanes	
n-Hexane	68.73_3	0.0419
2-Methylpentane	60.26_7	.0414
3-Methylpentane	63.25_6	.0418
2, 2-Dimethylbutane	49.80_4	.0411
2, 3-Dimethylbutane	58.02_2	.0417
	Isomeric heptanes	
n-Heptane	98.41_3	.0448
2, 2-Dimethylpentane	79.21	.0439
2, 3-Dimethylpentane	89.9	.0449
3-Ethylpentane	93.3_7	.0448
3-Methylhexane	91.8_8	.0445
2, 2, 3-Trimethylbutane	80.9_6	.0448
	Octane	
n-Octane	125.65_8	.0475
2, 2, 4-Trimethylpentane	99.23_4	.0465
	Isomeric nonanes	
n-Nonane	150.8_1	.0497
2-Methyloctane	143.2_6	.0495
3-Methyloctane	144.1_8	.0495
4-Methyloctane	142.4_9	.0492
2, 5-Dimethylheptane	135.2_1	.0489
2, 6-Dimethylheptane	135.2_1	.0490
	Isomeric xylenes	
o-Xylene	144.50	.0497
m-Xylene	139.10	.0491
p-Xylene	138.44	.0491

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FOUR HUNDRED WORD CHIN TAN OF CHANG PO-TUAN

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The alchemical treatise entitled *Chin tan ssŭ pai tzŭ* 金丹四百字 (Four Hundred Word *chin tan*) is ascribed to *Chang Po-tuan* 張伯端 (983–1082 A. D.), and is probably his genuine work. It exhibits his style and superior literary craftsmanship, and uses the same sort of vocabulary as the *Wu chên p'ien*[2] 悟眞篇 (Essay on the Understanding of the Truth). It consists of twenty poems of twenty characters each, and is thus much shorter and less pretentious than the *Wu chên p'ien*. It gives a less comprehensive account of the theory of alchemy and of its connotations and analogies, but there can be no doubt of the identity of the style and doctrine. It appears to be an earlier, tentative, and partial summary by the author who made in the *Wu chên p'ien* his final statement of the theory of the preparation of *chin tan* 金丹 (gold medicine).

The *Ming* 明 collection of works on alchemy, *Chin tan chêng li ta ch'üan* 金丹正理大全 (Comprehensive Account of the Genuine Preparation of the Gold Medicine), printed during the *Chêng-t'ung* 正統 reign (1436–1450), contains the *Chin tan ssŭ pai tzŭ* in two places. The section entitled *Tan shu* 丹書 (Papers on *tan*), which comprises about one-third of a volume in the second package, contains two articles of which the Four Hundred Word *chin tan* is one. No name of author or commentator is given; there is no preface and no date. The commentaries quote passages from the *Wu chên p'ien* but are briefer and less important than those of *Huang Tzŭ-ju* 黃自如 and *Liu I-ming* 劉一明, described below, and purport to be derived from two sources, *Nei tan* 內丹 (Treatise on Internal *tan*) and *Wai tan* 外丹 (Treatise on External *tan*), both of which are unknown to us. The other occurrence of the Four Hundred Word *chin tan* in the *Ming* collection is in *Chu chên hsüan ao chi* 諸眞玄奧集 (Collection of Papers on the Mysteries and Wonders of Various True Men), *chüan* 卷 1 of the third package, where the text is accompanied by the preface and commentaries of *Huang Tzŭ-ju*. We have also worked with a later *Ch'ing* 淸 edition, printed during the *Kuang-hsü* 光緒 reign (1875–1908), where the text is accompanied by the commentary of *Liu I-ming*. The *Ch'ing* text is identical with the *Ming* text except for a few places in which the commentator, *Liu I-ming*, seems to have substituted for the original characters different ones of the same meanings—and the substitutions in general have improved the sound of the poetry. In these cases, however, the commentator states that the passages were formerly written as we find them to be in our *Ming* edition, sometimes also that they were written in still other ways.

In his preface as published in the *Ming* edition, *Huang Tzŭ-ju* says that the book of *Yin fu* 陰符 (Amulets of *yin*) consists merely of three hundred words, and people have suffered from its simplicity. The book of *Tao tê* 道德 (The Way and its Power) contains five thousand characters, no less, and people have suffered from its complexity. Although the knowledge of *huang-lao*[3] 黃老 (alchemy, the art of making *chin tan*) has been circulated for several thousand years, yet it has not spread widely. During this period *Po-yang* 伯陽 opened its source and *Chung* 鍾 and *Lü** 呂 rippled its surface. "But their works cannot be compared with the Four Hundred Word

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[1] For the romanization of Chinese words we have followed the spellings which are used in Giles' Chinese-English Dictionary, 2nd ed., London, 1912. As this does not identify the words completely, we have printed the Chinese characters at the places of their first occurrence. Chinese personal names are given in the Chinese manner, family name first, thus *Chao Yün-ts'ung* 趙雲從. The Chinese characters have been borrowed from the fonts of the Harvard-Yenching Institute.

[2] Complete translation by *Chao Yün-ts'ung* with an Introduction by Tenney L. Davis, *Proc. Amer. Acad. Arts and Sciences*, *73*, 97–117 (1939).

[3] *Huang-lao*, the old name for Taoism, compounded from the names of *Huang-ti* 黃帝, legendary Yellow Emperor and reputed founder of alchemy, and *Lao-tzŭ* 老子, founder of Taoism, designates both the art and those who practice it. The name was used in this sense in the second century by *Wei Po-yang* 魏伯陽, the "father of alchemy," in the *Ts'an t'ung ch'i* 參同契; cf. *Isis*, 18, 239, 261 (1932).

* Compare footnote 1 of article (below) on "*Shih Hsing-liu*, Disciple of *Chang Po-tuan*," etc.

chin tan of *Chang* 張, *Tzŭ-yang* 紫陽 (pseudonym, Purple *Yang*), *chên jên* 眞人 (true man, sage) of our present dynasty, which includes the fundamentals of creation, penetrates the bone and marrow of *yin* 陰 and *yang* 陽, and is the stairway to *Tao* 道 and the road to the learning of the truth." Its words are not too numerous, but it has a keen initiative idea. "I have thought it over," he says, "three times, and love it so that I am going to write commentaries on it. Written in the first year of the *Shun-yu* 淳祐 reign (1241–1253) on the day of pure *yang* in the month of pure *yang* at *Chiang-ch'êng* 江城 by *Huang Tzŭ-ju*, a retired scholar."

Huang's preface in the *Ming* edition is followed by another preface, seven pages long, which purports to have been written by *Tzŭ-yang*. But the style of the writing and the nature of the discussion make it appear to be not his work. It states repetitiously the principles of *chin tan*, and quotes many times from the *Wu chên p'ien* without acknowledgement of source. It also contains the sentence, "Now I write the Four Hundred Word *chin tan* to include the fundamentals of creation and to penetrate the bone and marrow of *yin* and *yang*," and other expressions which occur in *Huang's* preface. It appears to have been written by *Huang Tzŭ-ju*. Moreover *Liu I-ming* says that *Tzŭ-yang* himself did not give any name to the work, but that the title of Four Hundred Word *chin tan* was assigned to it by his followers of later generations. *Huang* appends five poems of his own to symbolize the four signs and the five elements. Neither of our editions contains any preface by *Tzŭ-yang*.

In his preface in our *Ch'ing* edition *Liu I-ming* says that the Four Hundred Word *chin tan* is the composition of *Tzŭ-yang*, *chên jên*, of the *Sung* 宋 dynasty who wrote it after he had acquired the *Tao* and had transferred it to *Ma Ch'u-hou*[4] 馬處厚. In the beginning the work had no name, but because of its namelessness the followers assigned to it the name of Four Hundred Word *chin tan*. Its language is succinct, but its meaning is clear and easy to understand. It may be regarded as a sister piece to the *Wu chên p'ien* which classifies medicines, reagents and the fire and the season in detail, while this from beginning to end abstracts the main principle. The Four Hundred Word *chin tan*, from the time that it was first made known in the *Sung* dynasty, has been commented upon by various authorities, who, however, have given different explanations of the same sentences while none of them has got at the real meaning. "I do not wish the work of our ancestor to be buried and sunk, so I am explaining it in detail. As to what a *ting* 鼎 (tripod, furnace) is, what a furnace is, what the medicine is and what the fire is, I have made careful comments. These will make the reader clear with a single sight." The preface is dated the twelfth year (1807) of the reign of *Chia-ch'ing* 嘉慶 (1796–1821) in the month of the winter solstice. *Liu I-ming's* commentaries seem to us to be better than those of *Huang Tzŭ-ju*.

TRANSLATION AND COMMENTARY

Poem 1. True lead can be captured by true earth. True mercury can be detained also by making use of true lead. Whenever lead and mercury come into contact with true earth, the body and mind (heart) become perfectly motionless.

True lead and true mercury, not to be confounded with the materials ordinarily known by these names,[5] are the positive and negative principles respectively. They are induced to combine through the agency of some intermediary, true earth, the matchmaker, etc., and the product of their combination is *chin tan*, the perfect gold and the perfect medicine. This, in brief, is the essential doctrine of the *Wu chên p'ien* and of the Four Hundred Word *chin tan*. There also appear in the poems evidences of a theory as to how the intermediary works. True lead is fixed (as the European alchemists would say) by true earth; it may also be fixed, though with greater difficulty, by true mercury to which, however, it is given over by true earth. If the true lead and the true mercury are brought into contact with each other and with true earth, then each of the prime two is bound to the other, and the *chin tan* results. The true earth in this case acts as a catalyst or ferment or go-between.[6]

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[4] Compare paragraphs h and r of our paper on the *Wu chên p'ien*, *loc. cit.*

[5] "Our fellow-workers must be able to recognize the true lead and mercury, which are neither common cinnabar nor mercury," *Wu chên p'ien*, poem 8. "If you wish to inquire what the true lead is, the answer will be that the moonlight shines all day long on the western river," *ibid.*, poem 23. "In the use of lead it is not allowable to use the vulgar lead," *ibid.*, poem 26.

[6] In the tract, *de Alchimia*, Albertus Magnus says concerning the "four spirits of the metals, namely, mercury, sulfur, orpiment or arsenic, and sal ammoniac" that "these four spirits tincture (tint) the metals into white and red, that is, into Sun and Moon, but not by

Liu I-ming says that lead is heavy and inert and is likely to sink. Earth, which is located at the central position and is the mother of all creation, is able to regulate the four signs, and can be used to capture true lead and to sustain it from sinking. Mercury is an active substance, light, floating and easily lost. If it is detained by true lead, it will not fly or scatter away. Earth, lead and mercury are known as the three families, and are the three valuables of the human body. Lead and mercury, brought together into the earthen pot, are held safely and are undisturbed by passion.

The same commentator lists a number of terms which are synonymous with true earth, true lead and true mercury, and tells why they are used in this way. Many of them are terms which occur in the *Wu chên p'ien*. *Chung huang* 中黃 (yellow center, central yellow) signifies true earth because of its generative power, *huang t'ing* 黃庭 (yellow court) because of its ability to enter into anything, *tao kuei*[7] 刀圭 (a small spoon?) because it is the same whether it is in motion or at rest, and *huang p'o*[8] 黃婆 (yellow dame) (the matchmaker) because of its power of regulating *yin* and *yang*. Black tiger signifies true lead because of its inapproachable character, white tiger[9] because its *ch'i* 氣 (ethereal essence) belongs to gold, *chin kung* 金公 (golden fellow) because it is unconquerable, *shui chin* 水金 (watery gold) because its brightness is hidden in darkness, and *t'u* 兎 (rabbit) of the moon because it contains male elements within the female. Dragon[10] signifies true mercury because it goes back and forth without a definite hour, blue dragon because its *ch'i* corresponds to the eastern sky, scarlet dragon because it is formed by forging, *ch'a nü*[11] 姹女 (elegant lady) because it consists of *yin* inside of *yang*, *t'u* of the sun because it retains some female substance within the male, mercury of red because its truth resides in fire, and flowing pearl because its light penetrates everywhere.

Poem 2. *Hsü wu* 虛無 (empty-nothing) produces *pai hsüeh* 白雪 (white snow). Quietness causes *huang ya*[12] 黃芽 (yellow sprout) to bud. The fire of the jade furnace becomes hot and the purple vapor flies up from the *ting*.

Poem 3. Lotus flowers blossom at *hua ch'ih*[13] 華池 (beautiful pond). The golden ripples of *shên shui* 神水 (spiritual water) become quiet. The moon shines brightly at midnight. The heaven and the earth make a circular mirror.

Poem 4. Red cinnabar is used to compound the *ch'i* of *yang*, and quicksilver for the cooking of gold-essence. Gold-essence and the *ch'i* of *yang*—from red cinnabar to quicksilver.

According to *Liu I-ming*, false things can be changed into true things, and vice versa. The only difference is in the work of compounding, including the compounding of the inner self. If a man fails to compound his inner self, there may be reversal of the change, the *ch'i* of *yang* becoming red cinnabar and the gold-essence quicksilver.

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themselves unless they have first been prepared for this purpose with various medicines so that they will not escape from the fire. And when they have withstood the fire, they accomplish marvelous works, for they make Moon from Mars or Jove (silver from iron or tin) and Sun from Venus or Saturn (gold from copper or lead). . . . From these four spirits the tincture is made which is called Elixir in Arabic and Ferment in Latin." And concerning other spirits and medicines, namely, common salt, sal alkali, sal nitri, sal borax, alum, tartar, atrament, verdigris, calamine, copperas, tutia, cinnabar, minium, ceruse, vinegar, urine, cadmia, marchasite, magnesia, and others, he says: "These indeed do not tincture, but are spirit-adjuvants (*adiuuantia spiritus*), so that they are more readily prepared and more readily dissolved, and the calces of the metals are ground up with the waters of them and their substances take on a rectifying humidity." "Theatrum Chemicum," Ursellis, 1602, vol. 2, p. 495.

[7] This clears up the meaning of a passage in poem 70 of the *Wu chên p'ien*, "Call down the phoenix to drink the *tao kuei*." The phoenix is the volatile, positive principle, the true lead; make it fixed and non-volatile by letting it imbibe the true earth.

[8] "*Huang p'o* knows how to bring them together and how to enable them to marry with unchanging loving hearts, *Wu chên p'ien*, poem 36.

[9] "The white tiger is of the utmost value at the beginning," *Wu chên p'ien*, poem 84.

[10] In the *Ts'an t'ung ch'i* and in the *Wu chên p'ien* and elsewhere, dragon is always *yang*, positive, lead, sun, etc., and tiger is *yin*, negative, mercury, moon, etc. We are unable to explain the reversal of their ascriptions in the commentaries of *Liu I-ming*. The other synonymous terms appear to be correctly ascribed.

[11] "*Ch'a nü* travels in known directions. The first of her trips is short, whereas the later trip is long. When she returns, however, she enters the house of *huang p'o* and weds *chin kung* as her aged husband," *Wu chên p'ien*, poem 43.

[12] *Hsieh Tao-kuang* 薛道光, commenting on the *Wu chên p'ien*, says that *huang ya* is the *ch'i* of the dragon (hence true lead) and *pai hsüeh* the *ch'i* of the tiger (hence true mercury).

[13] *Hua ch'ih* is the place where the medicines are produced. "When he has finished the banquet at *hua ch'ih* where the moon shines brightly, he rides on a golden dragon to visit *tzŭ wei* (the star gods)," *Wu chên p'ien*, poem 63.

Poem 5. *Jih hun* 日魂 (soul of the sun), the fat of *yü t'u* 玉兎 (jade rabbit), *yüeh p'o* 月魄 (soul of the moon) and the marrow of *chin wu* 金烏 (golden crow). Collect them and put them into the *ting*. This then becomes a vessel filled with water.

Poem 6. Medicines produce the mysterious *ch'iao* 竅 (aperture, intellect, comprehension). The fire and the season develop in the *yang* furnace. When the dragon and the tiger end their meeting, the mysterious pearl is born in the golden *ting*.

The mysterious aperture, according to *Liu I-ming*, is a deep, hidden, small, obscure aperture at which *yin* and *yang* are separated from each other. *Hsüan p'in* 玄牝 (mysterious female), gate of living and dying, house of birth and death, and the aperture of *hsü wu* (empty-nothing) (the door of all wonderful) are other names of the mysterious aperture. The mysterious pearl is the *chin tan*, mysterious because its efficacy is so wonderful that it cannot be described by words, and pearl because it is round and of shining luster. The *Wu chên p'ien*, poem 83, says: "As early as the morning after the blending of mercury and lead, you will see signs of the formation of the mysterious pearl."

Poem 7. This *ch'iao* is not the common *ch'iao*. It comprises both *ch'ien* 乾, ☰ and *k'un*[14] 坤, ☷ (*kua* 卦 which signify heaven and earth), and is also known as the opening of *shên ch'i* 神氣 (spirit, expression, appearance) within which the essences of *k'an* 坎 ☵ and *li* 離☲ are found.

According to *Huang Tzŭ-ju*, this aperture of *hsüan p'in* does not belong to the material world. It appears in the body of a man before he acquires his body. It is located not above, not below, and not in the middle, but is a previous existence. According to *Liu I-ming*, the aperture is supremely mysterious and wonderful, and exists in an obscure, dark, mysterious and indistinguishable state of mind. If you wish to describe it, it will be lost. If you wish to criticize it, it will become non-existent. It is not a common material aperture which has a shape to be visible, or a solid body to be touchable. It is a sacred aperture which has no shape and no picture. It consists of the two *ch'i* of *yin* and *yang*. If a man does not possess it, as his generative power dies out, he will not be able to produce the medicine. The appelation, opening of *shên ch'i*, indicates its efficacy and admirable character.

Poem 8. A speck of wood-mercury red. Three catties of gold-lead black. Mercury and lead combine to form cinnabar which gives a permanent purple color.

The statement that (true) mercury and (true) lead interact to form (true) cinnabar or *chin tan* indicates that the true lead of the Chinese alchemists is the same as the sulfur principle of the Europeans, for ordinary mercury and ordinary sulfur do in fact interact to form ordinary red cinnabar. According to *Liu I-ming*, wood-mercury is the essence of *li* ☲. Its property is to float. Gold-lead is the essence of *k'an* ☵. Its property is to sink.

Poem 9. The scenery of your own garden is beautiful. In the spring there are favorable breezes and rains. It does not cost you much energy to plow and to dig. The whole area will fill up with yellow gold.

According to *Huang Tzŭ-ju*, one's own garden is the true earth of his own body, the scenery is the medicine, and yellow gold is the yellow sprout (*huang ya* or *chin tan*) which will bud up under the earth. *Liu I-ming* says that true lead and true mercury appear in a man's own garden, and that it is not necessary to seek for them elsewhere. This and several other of the poems suggest a parallelism between the processes for the attainment of the spiritual and the alchemical *Tao*.

Poem 10. True lead is produced in *k'an* ☵. It is used in the chamber of *li* ☲. Changing from black to red, the dense vapor and cloud fill up the *ting* completely.

Poem 11. True mercury is obtained from *li* ☲. Its uses, however, are in *k'an* ☵. *Ch'a nü* goes through the southern garden with a jade olive in her hand.

Liu I-ming says that the sentence, "*Ch'a nü* goes through the southern garden with a jade olive in her hand," means that efficacious wisdom loves genuine wisdom, and that genuine wisdom loves efficacious wisdom; indeed he has much to say in his commentaries about *hsing* 性 (nature of man) and *ch'ing* 情 (passion) and about genuine and efficacious wisdom. He appends to his commentaries on the Four Hundred Word *chin tan* twenty poems of his own, of the same style and substance except that the style is plainer and that genuine and efficacious wisdom are discussed.

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[14] The *Ts'an t'ung ch'i* commences with the sentence: "*Ch'ien* and *k'un* are the gateways to change." Later—"Hard *ch'ien* and soft *k'un* match and contain one another. *Yang* donates and *yin* receives." *Isis*, *18*, 231, 245 (1932). Also *Wu chên p'ien*, poem 18, "It is advised first that *ch'ien* and *k'un* be procured as the *ting* and the pot, and second that *wu* 烏 (crow) and *t'u* 兎 (rabbit) be put into them and treated in the same manner as in cooking. When you drive the two things into the *huang tao* 黄道 (yellow way), there is no reason why the *chin tan* will not form."

Poem 12. *Chên* 震 ☳ and *tui* 兌 ☱ do not indicate east and west. *K'an* ☵ and *li* ☲ do not indicate south and north. The handle of the Dipper turns around in the sky. A man is required who is able to coördinate.

According to *Liu I-ming,* the merit of putting them (the two contrary principles) together is his who understands the secret of heaven and turns the handle of the Dipper in the other direction.

Poem 13. The fire and the season are not necessarily at a definite moment.[15] The winter solstice is not at the hour of *tzŭ*[16] 子. The rule relative to the washing of the worker's body and hair will not be followed in vain at the hours of *mao* 卯 and *yu* 酉.

An understanding of the rule of creation by the universe teaches us, according to *Liu I-ming,* that the hour when the *ch'i* of *yang* starts to grow underneath the ground is known as *tzŭ,* and that at which the *ch'i* of *yin* starts to grow underneath the ground is known as *wu* 午 (the seventh double-hour, 11 A. M. to 1 P. M., midday). When the *ch'i* of *yang* rises into the heaven, the hour is *mao* (5 to 7 A. M.); when the *ch'i* of *yin* rises, it is *yu* (5 to 7 P. M.). *Tzŭ* and *wu* are the times at which *yang* and *yin* respectively begin to grow; *mao* and *yu* the hours at which they are in balance. These waxings and wanings are known as the *tzŭ, wu, mao* and *yu* of heaven and earth. Since *yin* and *yang* may grow up at any time, the hour is *tzŭ* whenever *yang* begins to develop inside a man's body, and the hour is *wu* whenever *yin* begins to gain in size. These are known as the living *tzŭ* and *wu* of the human body. There are many references to the hours in the *Ts'an t'ung ch'i.* It is surprising that so few additions to the doctrine and imagery of alchemy were made during the nine hundred years which intervened between that work and the writings of *Chang Po-tuan.* Putting the same proposition in another way, it is surprising that the *Ts'an t'ung ch'i,* the earliest known treatise on alchemy, should have a doctrine already so highly ramified and elaborated.

Poem 14. *Wu kan* 烏肝 (crow liver) and *t'u sui* 兎髓 (rabbit marrow) should be captured and put together in one place. Grain after grain, to large from negligibly small.

Wu kan is the essence of the sun, *t'u sui* that of the moon.[17] Grain after grain, *Liu I-ming* explains, means the gradual growing of the *ch'i* of *yang,* and is not to be understood as referring to grains or particles of any kind.

Poem 15. Primeval darkness includes *hsü k'ung* 虛空 (emptiness, a state of abstraction). *Hsü k'ung* includes the three worlds.[18] When you find out its source, it is only as large as a grain of millet.

Poem 16. Heaven and earth interlock the genuine fluid. The sun and the moon contain the genuine essences. Whoever understands the basis of *k'an* ☵ and *li* ☲, the three worlds will concentrate in his single body.

Liu I-ming says that anything within which *yin* and *yang* are present, anything which contains the genuine fluid and the genuine essence possesses the power of creation. *Yang* alone does not cause growth, and *yin* alone does not cause development.

Poem 17. The dragon comes from the eastern sea. The tiger rises up in the western mountain. The two creatures fight a battle and change into the marrow of heaven and earth.[19]

Poem 18. The golden flowers blossom among the perpetual leaves. Upon the jade stem, lead branches are growing. *K'an* ☵ and *li* ☲ never have leisure. How long would *ch'ien* ☰ (heaven) and *k'un* ☷ (earth) last?

According to *Liu I-ming,* golden flowers and lead branches belong to *yang* and are hard (strong). Perpetual leaves and the jade stem belong to *yin* and are soft (weak). *Li* ☲ has a hollow body and belongs to *yin.* *K'an* ☵ has a solid center and belongs to *yang.* The expression, "golden flowers blossom among perpetual leaves," means that hardness has some softness inside it. "Upon the jade stem, lead branches are growing" means that softness has some hardness inside it. "*K'an* ☵ and *li* ☲ never have leisure" means that solid contains some emptiness and that emptiness contains some solid. The genuine wisdom is the efficacious wisdom which can be hard and can also be soft, which can be empty and can also be solid.

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[15] "The glorious *chin tan* can be prepared and finished in any convenient day," *Wu chên p'ien,* poem 72.

[16] "At the time of the winter solstice, a single *yang* appears going in and out," *ibid.,* poem 90. "*Tan* is compounded at the moment when the single *yang* begins to appear," *ibid.,* poem 47. "The mysterious pearl increases as *yang* increases," *ibid.,* poem 48. The double-hour of *tzŭ,* 11 P. M. to 1 A. M. (midnight), is the first of the twelve periods into which the day was formerly divided.

[17] See the article, "Pictorial Representations of Alchemical Theory," *Isis,* *28,* 73–86 (1938).

[18] The three worlds are those of the passions, of visible things, and of invisible things.

[19] "The white tiger grows angry in the western mountains and the green dragon is irresistably fierce in the eastern sea. Capture them with both hands and let them fight to death. They then change into a layer of powder of purple gold," *Wu chên p'ien,* poem 37.

Poem 19. The washing of the worker's body and hair is for the purpose of guarding against danger.[20] The evacuation and addition should be carefully conducted by himself. As a rule, an error of a mere fraction in the thirty thousand quarters of hours is feared to be significant.

According to *Liu I-ming,* it is easy to recognize the medicines (reagents), but a knowledge of the fire and the season is extremely difficult. After the returning of the *tan,* the processes of washing the worker's body and hair must be carried out, and the operations of evacuation and addition. If the medicines are not in hand, the worker ought to compound them himself. When the *tan* has been formed, he ought to wash his body and hair in order to temper or anneal it (while no fire is maintained in the furnace). The returning of the *tan* is a matter of a single moment, but the tempering of it requires ten months, that is, thirty thousand quarters of hours—to every one of which the worker ought to pay strict attention to protect the *tan* from danger, as a hen does while hatching her eggs or an oyster while caring for its pearls. If anything wrong happens, the *chin tan* will be lost again from the previous gain, spoiled from the previous success. Guarding means to prevent the unintended growth of unknown *ch'i.* Danger is possible hurt to the vitality of the *tan.* Evacuation is the removal of the lead. Addition is the putting in of mercury. Before the *tan* crystallizes, lead must be used to detain the mercury. After the mercury has become dead, that is, after the *tan* has crystallized, it is necessary to draw off the lead.[21] This is the same as genuine wisdom being used to control efficacious wisdom. In this way, the latter will not scatter and fly away. When the efficacious wisdom has been made to condense (has taken concrete form), the previously used genuine wisdom, which contains cloudy (dirty) *ch'i* of the material world, must be removed little by little until not a single trace of it is left. The *chin tan* then ripens.

Poem 20. When the husband and wife live together, clouds and rain are produced in the bridal chamber. A child is born every year, and every one of these children is able to ride on the crane's back.

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[20] "At these times (the months of *t'u* (rabbit) and *chi* 鷄 (cock)) the man who is working on gold and cinnabar should stop his work, and wash his hair and his body. If fire is still applied, danger will certainly follow," *Wu chên p'ien,* poem 51.

[21] "The true lead after its use is nonetheless discarded. This is the rule of using lead. It is a sure statement that lead is used and is not used up," *Wu chên p'ien,* poem 26.

THREE ALCHEMICAL POEMS BY CHANG PO-TUAN

By Tenney L. Davis and Chao Yün-ts'ung

The present translation of three alchemical poems by *Chang Po-tuan* 張伯端 *P'ing-shu* 平叔 *Tzŭ-yang* 紫陽 completes the translation of all of his writings believed to be genuine which are known to us.

In the *Ming* 明 encyclopedia of alchemy, *Chin tan chêng li ta ch'üan* 金丹正理大全 (Comprehensive Account of the Genuine Preparation of the Gold Medicine), the *Wu chên p'ien* 悟眞篇 with its prefaces and commentaries occupies two volumes, and is followed by a third volume which bears the same title but which, however, is not the *Wu chên p'ien* and consists rather of an appendix of material supplementary to it. The first part of this appendix consists of three anonymous songs which are evidently the work of *Chang Po-tuan*, namely—*Tu chou i ts'an t'ung ch'i* 讀周易參同契 (On Reading the *Chou i ts'an t'ung ch'i*[1]) with commentaries by *Wêng Pao-kuang* 翁葆光 and *Tai Ch'i-tsung* 戴起宗, *Tsêng pai lung tung liu tao jên ko* 贈白龍洞劉道人歌 (A Song for *Liu*, a Comrade of *Tao*, of the White Tiger Cave) with commentaries by *Wêng* and *Tai*, and *Shih ch'iao ko* 石橋歌 (A Song about the Stone Bridge) with commentaries by *Tai*. The two latter songs are also printed again in the same *Ming* encyclopedia, without commentaries, in the section entitled *Ch'ün hsien chu yü chi* 羣仙珠玉集 (Pearls and Jades Collected from Various Immortals), where they are ascribed to the authorship of *Chang, Tzŭ-yang*. The two versions of the Song for *Liu* are entirely identical, but the two of the Song about the Stone Bridge differ in respect to several words but the alternative words have the same meanings and do not affect the translation.

The three poems exhibit the style of *Chang Po-tuan*, have the same high literary quality as the *Wu chên p'ien*, and make use of the same terms and imagery. The essay on Reading the *Ts'an t'ung ch'i* is written from beginning to end with only one kind of rhyme, in one tone and in one sound, as in English fun, gun, sun, etc. In our opinion it definitely helps to explain the meaning of the *Ts'an t'ung ch'i*. Its exposition of the general cosmological theory and of the theory of alchemy which is based upon it is succinct and especially clear. From the Grand One the two prime contrary principles are formed, and from these, represented by diversities of symbols, the *chin tan* 金丹 (gold medicine) is to be produced. The Song for *Liu* seems in large part like an abstract or summary of the *Wu chên p'ien*. The Song about the Stone Bridge is a lyrical exposition of the same doctrine.

On Reading the *Chou i ts'an t'ung ch'i*

The effective use of the great *tan* 丹 follows the method of *ch'ien* 乾 (a *kua* 卦, namely ☰ symbolizing heaven) and *k'un* 坤 (a *kua*, namely ☷ symbolizing earth). Behold, the revolving of *ch'ien* and *k'un* gives rise to the *wu hsing* 五行 (five elements). Behold, in the rise of the *wu hsing*, the eternal *Tao* 道 brings about creation and extermination. Behold, when the *wu hsing* are going backward, the body of *tan* is ever existing and ever efficacious. The Grand One which comes from *hsü wu* 虛無 (empty-nothing) shows the signs of the formation of the material. The *liang i* 兩儀 (the two prime contrary powers, two forms, two rules, two principles) then begin to multiply themselves from this One. The *ssŭ hsiang* 四象 (four signs) come hand in hand with the two bodies, and the eight *kua* are therefore their offspring. Thousands of things in creation are produced from change. Then, after that, fortune (germination), evil (extermination), regret and sorrow become apparent.

The common people have used this rule in everyday practice, but they do not know it. The sages, however, who can see the source and the origin, have been able to consult the principle of *ch'ien* and *k'un* which includes all the wonders of the *Tao* of change. Then they have entrusted the signs to scholars. With the union of *p'i* 否 (a *kua*) and *t'ai* 泰 (a *kua*), yin 陰 and yang 陽 follow in their decrease or increase. When *t'un* 屯 (a *kua*) and *mêng* 蒙 (a *kua*) are effective, then the time must be morning or evening (respectively). *K'an* 坎 (a *kua*) and *li* 離 (a *kua*) represent male and female; fire and water. *Chên* 震 (a *kua*) and tui 兌 (a *kua*) are the souls of the dragon and the tiger. Watch patiently the central chamber in which, with good luck, the yellow dress will be seen. Meeting excess, the indefinite position (fire?) will occur, and it should be respected.

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[1] The *Ts'an t'ung ch'i* (Akinness of the Trio) based upon the Book of Change of the *Chou* dynasty, written by *Wei Po-yang* 魏伯陽, English translation by *Wu Lu-ch'iang* 吳魯強 with an Introduction by Tenney L. Davis, *Isis*, 18, 210–289 (1932).

The *kua* of *chi* 既 and the *kua* of *wei* 未[2] take care of the process, from the beginning to the end of creation, for all things in the universe, while the *kua* of *fu* 復 and the *kua* of *kou* 姤 throw light on the two *ch'i* 氣 (ethereal essences) which are galloping. The waning and waxing of the moon will accompany the gain and loss of one's *ching shên* 精神 (mental energy). The rising and setting of the sun are designed to fit the body's seasons of health.

The original idea of the paper (*Ts'an t'ung ch'i*) was to set down words for the purpose of manifesting the picture (phenomenon). After you have understood the picture, the words should be forgotten. This is the same as drawing a diagram for showing an idea, and, after the idea has been made clear, the diagram should then be put away. Those who are clever will see them (the words) to be very simple and very easy, whereas the stupid ones will find them (the words) more and more complicated and difficult as they continue the study. Therefore, one can imagine that scholars competent at learning the truth will read the *Ts'an t'ung ch'i* and will not necessarily be restrained by its symbols and its words.

A SONG FOR *Liu*, A COMRADE OF *Tao*, OF THE WHITE TIGER CAVE

The running of jade, the flying of gold; the two luminous bodies move hurriedly. As soon as the news of the blooming of the flowers is heard, then the frost of the autumn follows closely thereafter. It was in vain that *Chien* 錢 was proud of his long life of a thousand years. For this is only as long as the glare of lightning upon the clouds. The glare of lightning! A great speed! A hundred years (of living) amounts to about thirty thousand days, during which the cold seasons and the hot seasons fry and boil (beat, press) one another. Imperceptibly boyhood vanishes easily into the silence. Even though you have many sons and grandsons before your eyes, yet your affection for them becomes a matter of anxiety. At the time when your energy is exhausted and when your body is going to decay, who then can teach you how to continue your life and to let yourself stay for a longer while? A longer while for staying! One has no means of contriving it! Eventually you will let your life go back like the passing of water down the stream.

Look at the ancient people, the saints and the sages. How many of them could know how to maintain their lives in the world? Maintain lives in the world! Yet means are available. However, it is ungratifying that the people nowadays are unthoughtful, and attempt to search for grass and wood[3] from the mountains.

Surrendering lead, controlling mercury, and staining the *tan* (medicine, red color) of *yang*. Stain the *yang tan!* It is an entirely different thing (from grass and wood). One must obtain the red blood from *k'an*, and must bring it over to the position of *li* for controlling the essence of *yin*. The matching and the blending should have their definite time. The time must be accurately chosen, and it is necessary that a matchmaker should be present. *Chin kung* 金公 (golden fellow) and *ch'a nü* 姹女 (elegant lady) will be made to marry each other. *Chin kung* likes very much to ride on the white tiger's back, whereas *ch'a nü* often drives about upon the body of the scarlet dragon.

The tiger comes down from the autumn mountain while the dragon goes up swiftly from the green gulf. The waves roll and roar like water boiling in a *ting* 鼎. *Huang p'o* 黄婆 (yellow dame, the matchmaker) and *ting lao* 丁老 (old fellow) then assist in striking up terror and in beating up power. *Ch'ien* and *k'un* heaven and earth) are then shaken up and the spirits and ghosts stir about.

After a while the battle ceases. The clouds and rains withdraw. The mysterious pearl is planted deeply in the soil. Its roots and sprouts grow out gradually. The *chên ching* 眞精 (true essence) is then used to irrigate it from time to time. After ten months it comes out from the womb, and is ingested by the mouth. He (the worker) then feels that his material body already possesses its efficacious properties.

This subject is little known in the world. It is unlikely that ordinary people will hear of it. If your former life has not given you in your bones an affinity for *hsien* 仙 (immortal, the qualities of *hsien*, the art of immortality), how can you meet it (the medicine) easily? When you meet it, you should work on the compounding—because time passes as fast as an arrow. Whenever one desires to catch fish, he ought first to construct the net. Otherwise, he can only sigh in vain beside the pond. I have heard that you, *Liu* comrade, have studied the medicines for many years. Why don't you concentrate your mind on the compounding of mercury and lead? Do not let the candle be blown out by the wind. Otherwise, on the six-fold way of *Lun-hui* 輪迴 (transmigration, the revolving re-union) one can be called only when it is too late to murmur to heaven.

Nowadays, people are becoming unreliable. All those who dress in cotton clothes, and pretend that they are Taoists, cannot answer even a word and keep their mouths shut as if they were dumb, when you choose to inquire of them about what *chin* 金 (gold) and *mu* 木 (wood) are going to be. They may mean the practices of taking doses of *ch'i* (ethereal essence) and of ceasing to eat food. But these are other doors and courts which lead one far away from success. Do you not see the teachings in the Song on Clearing Up Perplexity? The song suggests that the grand One, which contains the truth, is the best method. One should not say that the song's words are nonsense. The difficulty lies rather in the fact that the common people are unable to understand (recognize) them.

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[2] The *kua*, *chi* and *wei*, are not mentioned elsewhere in the writings of *Chang Po-tuan*. According to the commentator *Wêng Pao-kuang*, they are the last of the sixty *kua*, and the *kua* of *t'un* and *mêng* are the first two of them. They thus constitute a complete cycle of change.

[3] In order to attain longevity or immortality through the magic powers of these materials.

I know that you, *Liu* comrade, have the same mind (heart) as I do, and so I dare to discuss the subject with you frankly.

A SONG ABOUT THE STONE BRIDGE.

My home was originally established north of the Stone Bridge. The mountains ended there forming a water-gap upon which a forest of ancient trees was flourishing. Underneath the bridge there flowed a stream of water coming down from *K'un-lun* 崑崙 (a mountain range lying to the north of Tibet, where the Taoist heaven is located). Along the slopes of the hills, sweet springs full of fragrance were found. Over the hillsides, perpetual flowers were cultivated. I am proud of having lived in this valley.

In the cave on the north side of the mountain the fierce tiger dwelt, which, when it came out of the cave, roared to give wind and mist. On the south side of the mountain the dragon hid itself at the bottom of the gulf (pond). Whenever clouds were soaring aloft, whenever rain poured down and the sky was darkened and covered with mist, the two creatures met one another and fought a battle. At that time an auspicious omen of the formation of the mysterious pearl might be seen.

The landscapes were beautiful. I was inwardly glad. I poured my own wine and drank my own cup until I became completely drunk. After I was drunk, I played a song on the stringless lute. The lute seemed to warn with every bit of its voice that one must be careful. However, it was pitiful that no one among the drunken crew could understand. Stupid, silent as I was, I seemed to be crazy.

I looked above with my head raised, and I admired the excellence of the creation of the universe. The sun can be turned about to rise from the west, and the moon also can be reversed to set in the east. The heaven may become the earth, and the earth may become the heaven. The back-and-forth changes of *yin* and *yang* conform to the principle of nature. Anyone who is able to recognize the topsy-turvy-ness of the five elements will return to heaven's cave and will ascend to the clouds in the bright daylight. (In the heaven) there are houses built of yellow gold, beams made of white jade, and golden boys and jade girls who stand before you every day. There the southern stars and the northern Dipper are clearly visible, and there before your eyes appear endless scenes and thousands of views.

No day and no night. One's work should be carried on continuously. The concentrating and the scattering of the fire and the season of the heavenly cycle should be completed. If one wishes to inquire into the actual nature of *chin tan*, he should find a teacher who will disclose to him the secret of lead within water. Wood produces fire. Gold generates water. Water and fire are known to have the first and the second parts. One should be able to recognize the floating portion and the sinking portion, and to identify the host and the guest. When lead, silver, cinnabar and mercury begin to interlock, there are hard and soft constituents to which one should give attention.

Inwardly to be contented is always sufficient; and this will lead one to go back to the original position where thousands of gods are present to celebrate the peaceful years. This is the time when the country becomes rich and the people live happy lives.

This (art) is a matter for inference. Our comrades of *Tao* all know the idea. Yet, after they know it, a number of followers-of-learning-the-truth still prefer to practice the method of keep-on-thinking and of exercising the *ch'i* (ethereal essence). (But the art, the preparation of *chin tan*) is also very easy. Anyone who has taken the dose will realize its incomparable efficacy. It removes any illness at first, and then prolongs one's life. It is formed by cooking with fire, and is changed into a body of *yang* (i. e. into a mass of potency). Those who desire to learn *Tao* should think the matter over for themselves. Do not permit yourself to be ensnared by the small talismans of other doctrines.

If you know nothing else than that you are able to cheat people, you will soon witness the decay of your power of living. I suggest that the followers be ambitious. Do not desert your home to live somewhere else. The wonderful *Tao* exists not far away from your own body. It is not necessarily found in high mountains or in unknown waters. Do not delay lest you become worthless. Find a teacher as soon as possible, in order that you may acquire the principle of *hsüan* 玄 (mystery). If you do not learn the truth in your present life, how will you know in what womb you are going to be born in the next life? When you have decided to take up the subject, you must stick to it through to the end. The greatest of human events are life and death. If the almighty heaven is ungrateful to those who possess the heart of *Tao*, I shall be glad to be condemned to live as a mean ghost in *San-t'u* 三塗 (three mud).

SHIH HSING-LIN, DISCIPLE OF CHANG PO-TUAN AND HSIEH TAO-KUANG, DISCIPLE OF SHIH HSING-LIN

By Tenney L. Davis and Chao Yün-ts'ung

In the poem which *Liu I-ming* 劉一明 appends to his commentaries on the *Chin tan ssŭ pai tzŭ* 金丹四百字 (Four Hundred Word *chin tan*), he says that *Tzŭ-yang* 紫陽 (*Chang Po-tuan* 張伯端) gave his writings to *Ch'u-hou* 處厚 who did not understand them and thus did not become a *hsien* 仙. The teachings also influenced *Shih Hsing-lin* 石杏林 who got the idea and ascended.

The *Lieh hsien ch'üan chuan* 列仙全傳 (Complete Biographies of the Immortals) contains the following account of *Shih Hsing-lin*.

> *Shih T'ai* 石泰 was born at *Ch'ang-chou* 常州. He was also named *Tê-chih* 得之, and had the titles *Shih Hsing-lin* and *Ts'ui-hsüan-tzŭ* 翠玄子 (Green Element Fellow). He met *Chang* 張 *Tzŭ-yang* from whom he learned the *Tao* 道 of *chin tan* 金丹 (gold medicine).
>
> Originally *Tzŭ-yang* acquired the *Tao* from *Liu Hai-ch'an* 劉海蟾 who told him that whoever, at some time in the future, should untie his bridle (rope, fetters) and unlock his hands ought to be given this *Tao*. It ought not to be given to any others. At a later time *Tzŭ-yang* gave the *Tao* three times to persons who were not the right ones, and three times he met misfortune. He swore not to give the *Tao* carelessly again, and then wrote the *Wu chên p'ien* 悟眞篇 which has been circulated in the world. He says: "Anyone who has the spirit of a *hsien* and the bone of *Tao* will read it and will understand it himself." He then met another misfortune in *Fêng-chou* 鳳州. The administrative officer (prefect) became angry with him and convicted him by means of false evidence. He was transferred as a prisoner to another place. During the course of the trip, he came to *Pin* 邠. In a drinking place he made the acquaintance of *Shih Hsing-lin* and told him about the circumstance. *Hsing-lin* said that the administrative officer of *Pin* was a friend of his. He then explained the matter to the administrative officer, and a pardon was secured in consequence of this single visit. *Tzŭ-yang* thanked him and said: "If this great favor is not recompensed, I shall not be a man." He then gave all his *fa* 法 (methods, powers, demonstrations) of *tan* 丹 to *Hsing-lin*. *Hsing-lin*, after acquiring the *Tao*, wrote also *Huan yüan p'ien* 還源篇 (Essay on Returning to the Origin) which has been circulated in the world. He attained an age of one hundred and thirty seven years. He died in the twenty-eighth year of the *Shao-hsing* 紹興 (1131–1163) reign of the Emperor *Kao-tsung* 高宗 of the *Sung* 宋 dynasty. On the day of mid-autumn two years later, *I Chieh* 易介 saw *Hsing-lin* again in *Lo-fu* 羅浮 mountain.

The Record of the City of *Fu-fêng* 扶風, in *Shan-hsi t'ung chih* 陝西通志 (General Record of *Shensi* Province), *chüan* 卷 65, section *shih tao* 釋道, written in the middle of the *Ch'ing* 清 dynasty by *Liu Yü-i* 劉於義, contains substantially the same account of *Shih Hsing-lin*. It states that he was a medical doctor. He did not accept fees from the persons whom he treated, but told them to plant apricot trees in his garden. The garden finally became a forest of apricots, whence he derived his name of *Hsing-lin* (which means forest of apricots).

Huan yüan p'ien (Essay on Returning to the Origin) is printed in the *Ming* 明 collection, *Chin tan chêng li ta ch'üan* 金丹正理大全 (Comprehensive Account of the Genuine Preparation of the Gold Medicine), in the section entitled *Chu chên hsüan ao chi* 諸眞玄奧集 (Collection of Papers on the Mysteries and Wonders of Various True Men), *chüan* 2 of the third package, eighty one short poems without commentary, with an undated preface and an appendix by *Shih Hsing-lin*. The author states that he has written the essay for the purpose of instructing disciples of later times so that they may be able to understand the true secret as early as possible and not have to wait until they are old when the mercury and the lead in their bodies become weak and less abundant. A few of the poems have been translated as typical.

> Poem 2. Mercury is the marrow of the green dragon. Lead is the fat of the white tiger. Procure them and put them into the *ting* 鼎. However one should know the hours for the selection and the collection.
>
> Poem 8. The water of *k'un* 坤 (a *kua* 卦, ☷) is used for washing the worker's body and hair. The wind of *hsün* 巽 (a *kua*, ☴) is used for blowing and fanning (the fire). *Ying êrh* 嬰兒 (infant) has nothing to do but lives alone in the chamber of *t'ai wei* 太微 (very small).
>
> Poem 27. The mercury in the *yen yüeh lu* 偃月爐 (lie-down-moon furnace), the lead in the *ting* of cinnabar and the only single genuine *ch'i* 氣 (ethereal essence) of the tortoise and the snake. They are produced before life.

Poem 38. *Shên shih* 神室 (chamber of efficacy) is neither the spleen nor the stomach. The bladder serves no more than to assist the kidney. I advise you not to hold on obstinately, for these are not the axis of *tan.*

Poem 51. The black mercury produces yellow leaves. The red lead blossoms with purple flowers. Attention to the fire and the season is needed. The *tan* cinnabar will crystallize within the *ting.*

Poem 63. Although creation starts without anything, *yin* 陰 and *yang* 陽 have their source. The real wonders here are not supposed to be taught to others, not even by a father to his son.

Poem 79. *Lü*[1] 呂 was given oral instruction by *Chung* 鍾. *Ko*[2] 葛 got the vital secret from *Chêng* 鄭.

There is not much to discuss. All that they used was only mercury and lead.

Poem 80. Put mercury and lead into the same *ting.* The sun and the moon should be (compounded) in a single furnace. During the starting of the fire, the worker should take precautions. Then you learn the method of giving form to the jade pastry.

The *Lieh hsien ch'üan chuan* contains no biography of *Hsieh Tao-kuang* 薛道光. The General Record of *Shensi* Province, *loc. cit.*, states that *Hsieh Tao-kuang* had other names, *Shih* 式 and *Tao* 道. He was born at *Chi-tsu-shan* 雞足山 (Chicken foot Mountain) in *Shan-fu* 陝府 of *Shan-hsi* 陝西 (*Shensi*) Province. For a time he was a Buddhist monk, having the title *Tzŭ-hsien* 紫賢 (Purple Gentleman). He lingered in *Ch'ang-an* 長安, the capital of Shensi Province, and interested himself deeply in the *chin tan* medicines. In the winter of the fifth year of the *Ch'ung-ning* 崇寧 reign (1102–1107) of the Emperor *Hui-tsung* 徽宗 of the *Sung* dynasty, he lived in the city of *Mei* 郿, and there he met *Shih Hsing-lin.* At that time he received from *Shih Hsing-lin* oral instructions in the true essentials. He later commented on the *Wu chên p'ien* and wrote *Fu ming p'ien* 復命篇 (Essay on Fulfilling the Will of Heaven) and *Tan sui ko* 丹髓歌 (Song on the Marrow of *tan*). He attained an age of one hundred and fourteen years.

The two poems of *Hsieh Tao-kuang* are printed (under titles slightly different from those cited above) in the *Ming* collection, in the same section with the poem of *Shih Hsing-lin, chüan* 3 of the third package. *Huan tan fu ming p'ien* 還丹復命篇 (Essay on the Returned Medicine for Fulfilling the Will of Heaven) is preceded by a preface of *Hsieh Tao-kuang,* dated in the autumn of the year *ping wu* 丙午 of the *Ching-k'ang* 靖康 reign (1126–1127), and is followed immediately by the *Tan sui ko* 丹髓歌 (Song on the Marrow of *tan*).

Hsieh Tao-kuang states that he wrote *Huan tan fu ming p'ien* according to the oral instructions of his late teacher, first, sixteen poems to represent two-eight which makes a catty, second, thirty more poems to represent the thirty days employed for accomplishing the great merit (of compounding) and third, nine poems further to represent the method of nine changes. The following are representative samples.

Poem 1 of First Part. There is something which implies the substance of efficacy. It has no name but is derived originally from nature. The scarlet dragon hides in the universe, whereas the white tiger conceals itself in the field of *tan.* As far as in the northern constellations and the southern stars, as near as on your eyebrows and eyelashes. You should manage the fire and the water patiently, and search for the true lead with concentrated energy.

Poem 13 of the First Part. It depends upon your skill. Your energy should be kept in mind. *K'an* 坎 and *li* 離 frequently make use of one another. Gold and wood desire to interlock with one another. *Pai hsüeh* 白雪 (white snow) can be put (with chemicals) into a *ting.* *Huang ya* 黃芽 (yellow sprout) can grow (with medicines) in one budding. *Ch'ien* 乾 and *k'un* map the numbers nine and six. The *kua* of *fu* 復 and *kou* 姤 move the first *yao* 爻 (lines which compose the *kua*).

Poem 1 of Second Part. Things in the universe are all produced from the single *ch'i* (ethereal essence) which embodies both the will of the clear sky and the will of the clouded earth. After the true dragon and the true tiger have just interlocked, a *ting* filled with red lead should be compounded with *chia* 甲 and *kêng* 庚 two symbolic figures).

Poem 5 of Second Part. The chamber of *li* has a picture inside which the true water is present. The gate of *k'an* does not produce a form within which the scarlet dragon hides. They must be collected as soon as possible at the correct hour. Do not let the buds and the stumps remain long enough to touch the yellow chamber.

Poem 8 of Second Part. Hunt for the something in the state of obscurity. Recover the true essence from the indistinct world. The true essence therefore is the medicine of long life. However, it must borrow the help of *huang p'o* 黃婆 (yellow dame, the matchmaker) to be brought up.

Poem 6 of Third Part. When bamboo ware is broken, bamboo is needed for the repairing. When a man's energy wears out, lead is required for re-strengthening. Think the matter over. (The medicine) may be found directly in front of your eyes. The trouble is that the common people cannot perceive it.

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[1] Evidently *Lü T'ung-pin* 呂洞賓 and *Chung-li Ch'üan* 鍾離權.

[2] *Ko Hung* 葛洪 was instructed by *Chêng Chün* 鄭君, *Chêng Yin* 鄭隱 or *Chêng Ssŭ-yüan* 鄭思遠, concerning whom he writes in *Pao-p'u-tzŭ* 抱朴子. Cf. *Proc. Amer. Acad. Arts and Sciences, 70,* 235, 252, 256, 260–1 (1935).

The sun and the moon interlock at *k'an* and *li*. The dragon and the snake are produced before life. The wonderful pill of longevity occurs in your own house and yard. It may appear in a single moment.

Tan sui ko consists of thirty four stanzas of which four are now translated.

Stanza 1. The compounding of *tan* need not commence on the day of the winter solstice. Naturally a single *yang* will develop within your body. The dragon flies above the scarlet water on which waves and surges rush. The tiger roars in the mountain of *tan* where there are clear dew and wind.

Stanza 7. The *wu* 烏 (crow) does not possess a shape, and the *t'u* 兔 (rabbit) fails to exhibit a form. *Wu* and *t'u* are simply the essences of the sun and the moon, the interlocking of which causes the eternity of heaven and earth.

Stanza 9. The tortoise does not show a picture and the snake goes away without a trace. Tortoise and snake are merely forms of *yin* and *yang*, of the two *ch'i* which would intermingle into one.

Stanza 11. Lead is not mercury, and mercury is not lead. Lead and mercury are procured within your body. It is essential that the body and the mind become motionless.

THE SECRET PAPERS IN THE JADE BOX OF CH'ING-HUA

By Tenney L. Davis and Chao Yün-ts'ung

The treatise entitled *Yü ch'ing chin ssŭ ch'ing hua pi wên chin pao nei lien tan chüeh* 玉淸金笥青華秘文金寶內鍊丹訣 (The Secret of Compounding Internal *tan* of the Golden Treasure from the Secret Papers in the Clear Jade Golden Box of *Ch'ing-hua*) exists in a *Ming* 明 edition of 3 *chüan* 卷 or chapters in 3 volumes, and purports to be the work of *Tzŭ-yang* 紫陽, *chên jên* 眞人, *Chang* 張, *P'ing-shu* 平叔. His name is printed on the title page and at the beginning of each of the volumes, but the literary workmanship of the piece is markedly inferior to that of the *Wu chên p'ien* 悟眞篇, and the style, the vocabulary, the doctrine, and the method of treating alchemy are all different from those of *Chang Po-tuan* 張伯端. We believe that the work is falsely ascribed to him. At the same time the treatise possesses real interest, for it is undoubtedly of the *Ming* dynasty, and it illustrates the intellectual vagaries to which the alchemists, Chinese and European alike, were often disposed. A somewhat detailed analysis of it is distinctly worth while in order that its true character may be known and in order that our reasons for believing it to be the work of someone other than *Chang Po-tuan* may be made more clear.

The work commences with an introduction in which the author, allegedly *Chang Po-tuan*, says—

> Yesterday I was given the secret of compounding internal *tan* 丹 of the *chin pao* 金寶 (golden treasure) for seeking the method of long life and independence of the material world out of the clear jade golden box of *Ch'ing-hua* 青華, the *chên jên* whose name is *ch'ing-hua*. . . . Recently I informed heaven that I was going to disclose this secret by writing it on paper and by setting forth the principle with pictures, for the purpose of instructing all followers who should be qualified. I lay on the bed in my straw house awaiting the penalties which should arrive from heaven for disclosing the secret. After a period of thirty days no penalties had yet come. I then washed my body and hair, and dared to start the writing. After three days the work was finished, and I kept it in the secret box of *fa* 法 (talismans) waiting to give it to the right man. I ask the kind forgiveness of heaven so that everyone will follow this method of compounding the golden treasure and will acquire longevity. . . . After I comprehended the secret of *chin tan* 金丹, I frequently met calamities from heaven. I also wrote the *Wu chên p'ien* and other papers which are circulating in the world. I have satisfied myself now.

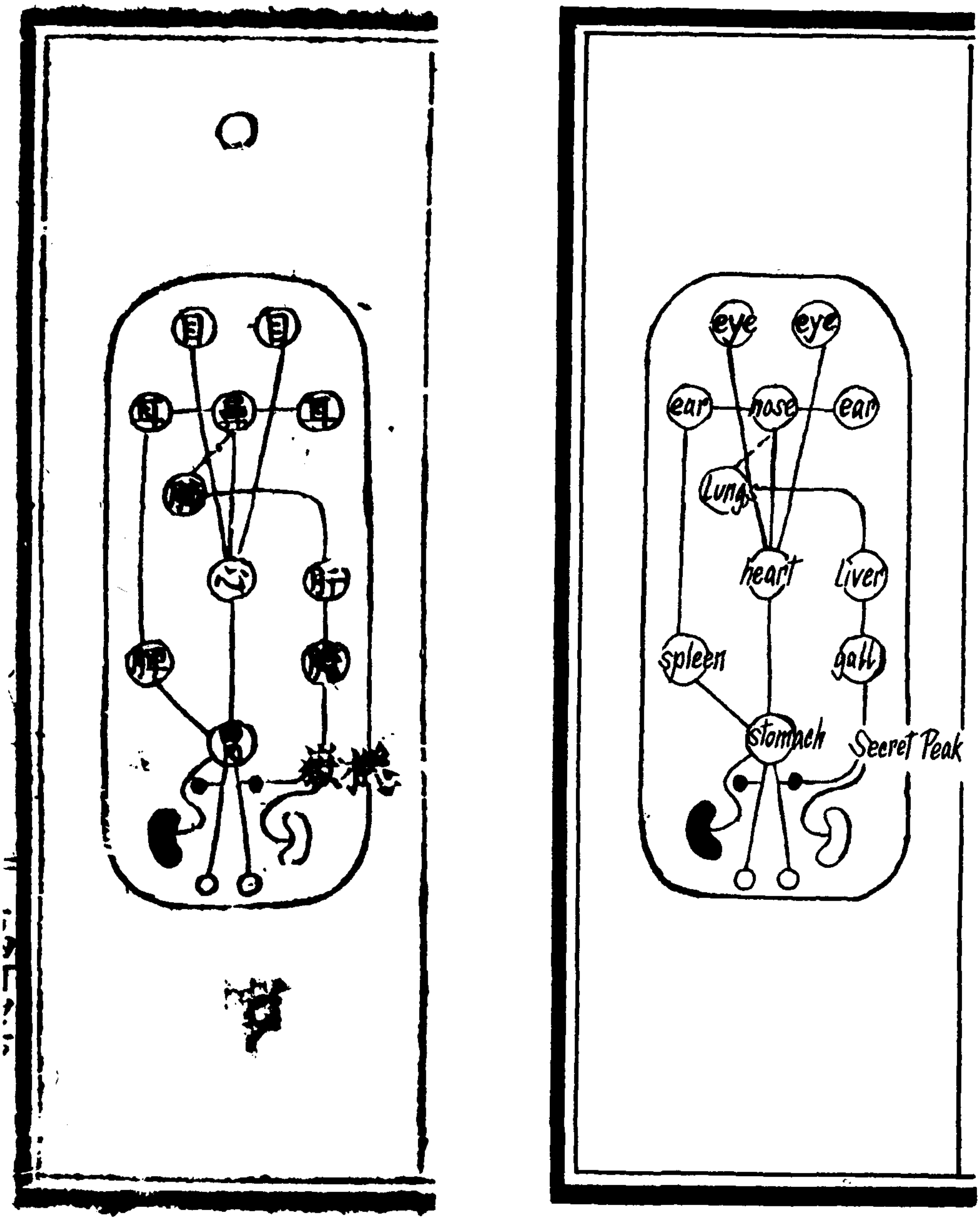
The introduction contains glaring inconsistencies. Indeed the whole work is poorly organized. The author asserts that he learned the secret yesterday, that he then waited thirty days, which is clearly impossible, and that he wrote the book of three volumes in three days, which is extremely unlikely. Perhaps the account is intended to point to the miraculous powers of the writer. He had a ridiculous fear of heaven, entirely unworthy of *Chang Po-tuan*. He states that he learned the secret from the jade box of *Ch'ing-hua, chên jên*, but *Tzŭ-yang* actually received his instruction from *Liu Hai-ch'an* 劉海蟾. The *Wu chên p'ien* which, he suggests, he wrote before the present treatise, was not immediately circulated in the world but was given to one man, namely, *Ma-mo Ch'u-hou* 馬默處厚, and was later transferred by the Taoists from hand to hand. After he wrote the *Wu chên p'ien*, *Chang Po-tuan* was a famed teacher and had *Ma-mo Ch'u-hou*, *Lung-t'u-lu-kung* 龍圖陸公 and *Shih Hsing-lin* 石杏林 as his disciples and sympathetic friends. They were men of position and wealth, and it is improbable that *Chang Po-tuan* was obliged to live in a humble straw house.

The introduction contains a diagram entitled "Mystery of Mysteries" which consists simply of two large circles one above the other.

The argument of the work revolves around the ideas of *ch'i* 氣 (ethereal essence), *shên* 神 (facial appearance) and *ching* 精 (essence) and makes use of anatomical and religious terms and analogies in a manner which is foreign to the thought of *Chang Po-tuan*. The expressions, *Chin pao* (golden treasure) and *huang t'ing* 黄庭 (yellow court), which appear frequently in the text do not occur at all in the *Wu chên p'ien*.

The following is a brief survey of the several parts of the treatise.

1.) Mind is the key. *Chang P'ing-shu* was able to stand his physical strains in his old age because he could fix his mind, that is, because he was able to avoid excessive thinking. If one can quiet and appease the mind, *chin tan* will be acquired without working on it. *Shên, ch'i* and


eye
eye
ear
nose
ear
Lung
heart
Liver
spleen
gall
stomach
Secret Peak

a

b

FIGURE 1. Anatomical diagram showing connections between various organs. One kidney is black and is connected with the stomach; the other is white and is connected with the gall bladder through the "secret peak." (The term which is translated secret also means mechanism, vitality, chance and moment.)

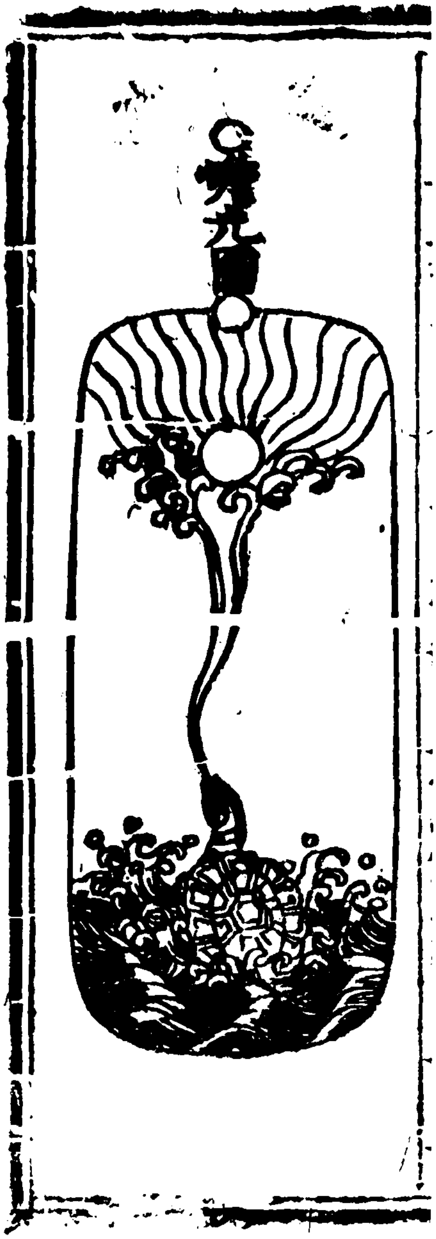


FIGURE 2. Alchemical diagram representing the combination or interaction of the *yin* and *yang* principles.

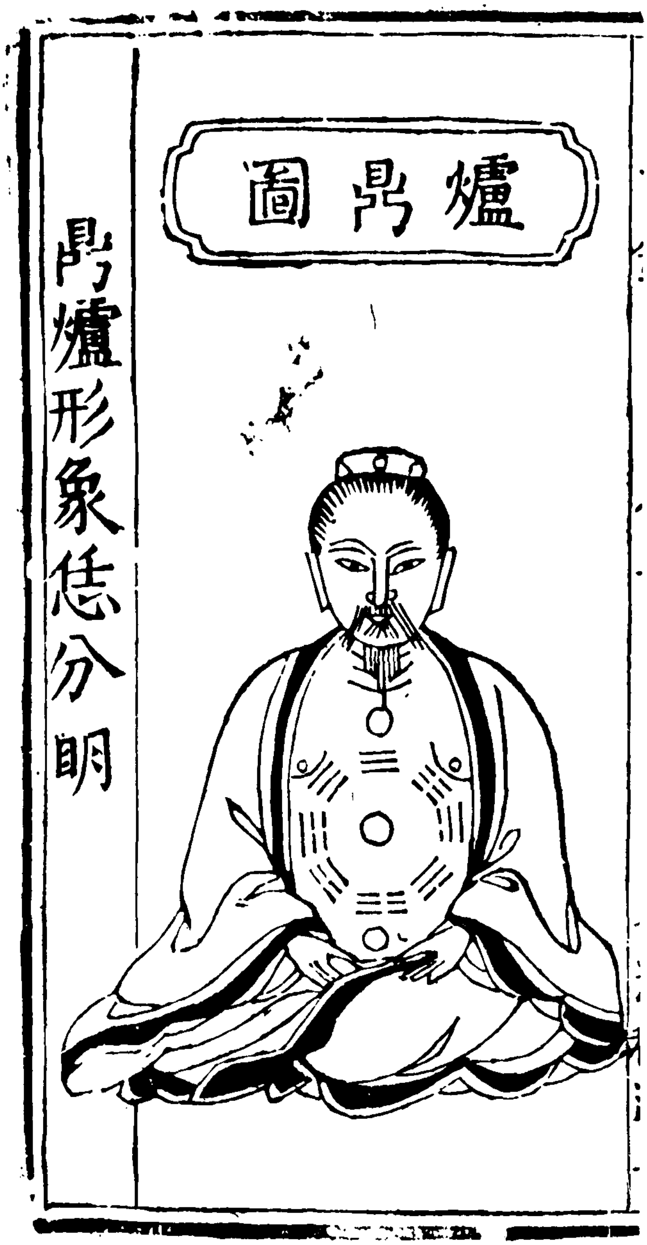


FIGURE 3. Diagram of the furnace and the *ting*. Eight *kua* are represented but only six different ones altogether, for two of them are repeated. The *ch'ien kua* at the top is completely *yang* and represents heaven. The *k'un kua* at the bottom is completely *yin* and represents earth. The legend at the side says: "This *ting* and furnace picture is as clear as is indicated here."

ching will obey the mind if the mind is intent upon them.

2.) *Shên* (appearance) is the main factor. There are two kinds of *shên,* the primary *shên* and the lustful *shên.* The primary *shên* is the spot of efficacious light which is formed before life, and is natural. The lustful *shên* is the character formed from *ch'i,* and is artificial. Things which are formed before life should be used to control those which are formed after life.

3.) *Ch'i* is of utility. There are *ch'i* of before-life and *ch'i* of after-life. The primary *ch'i* is formed throughout the body, but it should be obtained from the kidney. The reasons are 1.) that the path of the kidney reaches straightway to the aperture of *ch'i,* 2.) that the kidney is the source of essence, 3.) that the *ch'i* can be recognized easily in the place of the essence, and 4.) that the *ch'i* of mind (heart) penetrates the kidney and thus is collected more easily at the kidney. Therefore, there are these four reasons for collecting *yin* 陰 and *yang* 陽 at the kidney.

4.) *Ching* (essence) follows *ch'i* (ethereal essence). *Ching* grows from *ch'i* and fills the kidney in an atmosphere of *ch'i.* When the essence is lost, the *yang* principle will not form. Primary *ch'i* grows in the presence of primary *shên,* and primary *ching* forms in the presence of primary *ch'i.*

5.) *K'an* 坎 and *li* 離 (two of the *kua* 卦). *K'an* represents the chamber of the kidney, and *li* the field of the mind. Feeling grows in the mind and descends to the kidney. *Yang* is produced in the kidney and ascends to *huang t'ing*[1] 黃庭 (yellow court).

6.) *Ching* and *shên* (appearance). Many of of those who work on *tan* are ignorant of the method of fixing *shên.* This does not depend upon swiftness or slowness. The fixing consists in condensing *shên* into the interior of the essence. Fixing *shên,* in other words, is extinguishing all desires and returning *shên* to the mind. When this is done, one may see the whole figure of *hsing* 性 (character, nature). "Dissolve *shên* in *ching* and *ch'i,* and combine them into one. Then *yang* begins to form and your body (material) becomes useless (you become a *hsien* ?). I heard this from my near teacher; my near teacher heard it from a far teacher who in turn heard it from heaven."

7.) False *tan.* False *tan* will result from wrong collection and selection, when the worker's mind is not yet fixed and the single *yang* is a false *yang.*

8.) The technique of catching *tan.* *Chin tan,* which resides within, can also be lost. "When you feel your *ch'i* scattering about without inner influence, then your *tan* has gone away. It may be hiding in the heart, in the liver, in the stomach, in the kidney or in the apertures of your body. When you know where the *tan* is, you can collect it back by means of feeling (exercise of will) through a long period of time, into the chamber of *yang* and then into the *yang ting* 陽鼎."

9.) Spiritual water and beautiful pond. Spiritual water is the fluid of wood, and beautiful pond is the aperture which is located in the abdomen. The former is used to irrigate the furnace and the *ting* (tripod, furnace pot) and to wash the stomach.

10.) Hundreds of apertures. In the human body there are eighty four thousand hair holes and three hundred and eighty four air chambers. All these apertures can hold the *tan.* (This completes the first volume.)

11.) Diagram of collection and selection. Collection is the collection of the true *yang* in the kidney; selection is the selection of the true mercury in the field of mind. "I drew a diagram to show them and to disclose the secret of heaven." The growth of *yang* occurs when the *ch'i* of before-life flows out from the spring of *ch'i* to reach the kidney, similar to spraying. Mercury is produced in the heart. The accompanying picture represents a man sitting Buddha-wise, a gown over his shoulders, a crown on his head and symbols on his chest and abdomen, namely, two small white circles (above and below), four small black squares (two on each side) and a pot or cauldron (center).

12.) Diagram on interlocking. "Whenever you get oral instruction on the secret, do not write it on paper. If you do write it, do not let it be seen by others. I followed my teacher for ten years,[2] and I wrote down all that I learned in order that my comrades might keep it." The author mentions a diagram, which he says is very important, but no diagram is given.

13.) Diagram of disclosing the secret of heaven. The anatomical diagram reproduced in Figure 1, with commentaries devoted largely to a discussion of *shên.*

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[1] According to *Liu I-ming* 劉一明, *huang t'ing* means *chin tan.*

[2] There is no tradition that *Chang Po-tuan* ever followed a teacher for ten years.

14.) Diagram of the light of the toad. Long commentaries dealing with primary *shên*, artificial *shên*, *ch'i*, etc. Although the diagram, Figure 2, is entitled the light of the toad, the creature which is represented is clearly a tortoise. Toad and tortoise both appear in the *Wu chên p'ien* as symbols of the *yin* principle. The diagram has real alchemical significance, and represents the combination of the heavy, tortoise, inert, watery, mercury, *yin* principle with the light, active, fiery, sun, lead, *yang* principle.

15.) Diagram of the furnace and the *ting* 鼎. Long commentaries dealing with *huang t'ing* (yellow court), the aperture of *ch'i*, etc. In the picture, Figure 3, eight *kua* are shown, that which is completely *yang*, made up of three unbroken lines, being at the top, and that which is completely *yin*, made up of three broken lines, being at the bottom. But other combinations of *yin* and *yang* are needful, or at least useful, for the preparation of *chin tan*.

16.) Diagram of *shên shih* 神室 (chamber of *shên*, efficacious chamber). Lengthy commentaries. The diagram represents a man sitting Buddha-wise, a gown over his shoulders, and on his chest and abdomen four symbols, namely, reading downward, a small white circle, a small white rectangle, a small white square, and a small white circle. (This completes the second volume.)

17.) Diagram of the fire and the season. Long commentaries dealing with the *kua*, the planets, *ch'i*, the hours, the kidney, rising and sinking, gentle fire and drastic fire. The accompanying picture represents a man sitting Buddha-wise, a gown over his shoulders and a small crown on his head, on his chest and abdomen a symbol made up of a down-pointing triangle with a small circle at its lower tip, another circle at the middle of its horizontal upper side and a third circle directly above this one and connected to it by a short straight line.

18.) Diagram of the exhaustion of *yin*. Long commentaries dealing with the bandits of the six lusts. The picture shows a man sitting Buddha-wise with a crown or cap on his head, gown over his shoulders, and on his chest and adbomen three symbols, above a small white circle, below another somewhat larger, and in the middle two concentric circles with radiating wavy lines.

19.) Diagram of pure *yang*. The commentary states that there is no commentary. The picture, which is without symbols, represents a man, with his gown covering both the top of his head and his shoulders, sitting in calm Buddhistic meditation.

20.) General discussion of the essentials of *chin tan*. The *Tao* 道 of *chin tan* depends upon the materials, and the materials in their turn depend upon *ching*, *ch'i* and *shên*. These are of different kinds, both primary and secondary. *Ching* is condensed by *ch'i*. *Shên* is accumulated by *ch'i*. *Ching* dissolves in *ch'i*, and *ch'i* becomes useful through the presence of *ching*. *Ch'i* can be made visible by means of *shên*, and *shên* becomes useful through the presence of *ch'i*. The great medicines are no more than *ching*, *ch'i* and *shên*.

21.) Description of the nine changes. Nine paragraphs discussing changes from the ribs to the abdomen and kidney. End.

A FIFTEENTH CENTURY CHINESE ENCYCLOPEDIA OF ALCHEMY

By Tenney L. Davis and Chao Yün-ts'ung

Occidental students of the history of chemistry are acquainted with the names of less than a dozen Chinese alchemists, with accounts of the activities of scarcely half that number, and with considerable portions of the contents of the writings of only three.[1] They are aware that the Taoist Canon contains many treatises on alchemy, probably the principal portion of all of the Chinese writings on the subject, but the titles do not indicate the contents with certainty, and the names of the works and of their authors are still unknown. Under these conditions a list of the works which an ancient compiler thought proper to select and to publish together in a *Ming* 明 encyclopedia of alchemy is believed to be a definite contribution.

The collection, *Chin tan chêng li ta ch'üan* 金丹正理大全 (Comprehensive Account of the Genuine Preparation of the Gold Medicine) consists of twenty four volumes, divided among four packages of six volumes each, and pertains entirely to theoretical or speculative alchemy. It contains no practical chemistry, and is to be compared to the *Artis Auriferae* or the *Museum Hermeticum Reformatum* which it resembles in many ways. Professor *Huang Tzŭ-ch'ing* 黃子卿 of *Tsing-hua* 清華 University, who procured these books for us in Peiping and who is an expert on early Chinese printing, states that they were printed during the reign of the *Ming* emperor *Ying-tsung* 英宗 with the reign title *Chêng-t'ung* 正統 (1436–1450).[2] The collection was edited by *Han-ch'an-tzŭ* 涵蟾子 of *Tzŭ-hsia* (Purple Mist) Mountain, but no further information concerning him is given. We have not been able to learn anything concerning him from the several dictionaries of names which we have consulted.

The contents of the collection, *Chin tan chêng li ta ch'üan*, are as follows.*—

I. *Chin tan ta yao* 金丹大要 (Essentials of the Gold Medicine), written by *Shang-yang-tzŭ* 上陽子 during the *Chih-shun* 至順 reign (1330–1333) of the *Yüan* dynasty, 10 *chüan* in 5 volumes. [*Tao tsang* 736–738; °*yao* 昴 1–3.]

Chüan 1.

1.) Preface by the disciple *Ch'an T'ien-ts'ung* 蟾天琮, 2¼ pages.[3]

2.) Preface by the disciple *Ou-yang T'ien-ch'ou* 歐陽天疇, 2 pages.

3.) Preface to the *Chin tan ta yao* by *Shang-yang-tzŭ*, *Ch'ên Kuan-wu* 陳觀吾, *Chih-hsü* 致虛 of the Pink Palace of the Purple High Sky, 10¾ pages.

4.) Preface by the same on the Book of *Tao-tê* 道德, 5½ pages.

5.) Explanation by the same of the Chapter, "*Tao* may be *Tao*," 4 pages.

Chüan 2.

1.) Supreme medicines possess the three properties, or the theory of *ching* 精 (essence), *ch'i* 氣 (ethereal essence) and *shên* 神 (appearance), 13½ pages.

Chüan 3.

1.) Efficacy in using *chin tan* 金丹 (gold medicine), 1½ pages.

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[1] Namely, 1.) *Wei Po-yang* 魏伯陽, 2.) *Ko Hung* 葛洪, or *Pao-p'u-tzŭ* 抱扑子 and 3.) *Chang Po-tuan* 張伯端, otherwise *Tzŭ-yang* 紫陽, otherwise *P'ing-shu* 平叔.

[2] A manuscript note in the first volume, written in red ink at the end of the second *chüan* 卷, reads as follows—"These books were purchased in the third month of the twenty-third year of the *Chia-ch'ing* 嘉慶 (1796–1821) reign at a price of ninety *liang* 両 of silver. The outer covers and the punctuation (putting in red) were made in the fifth month of the sixth year of the *Tao-kuang* 道光 (1821–1851) reign. *Ch'io-li-tzŭ* 確立子 (Strict Decision Fellow), the library of *An-lo* 安樂 (Happiness), Western Garden, *Tung-wu* 東屋 (Eastern House) Village, *Kuei* 龜 (Tortoise) Mountain of *Li-nan* 歷南 (in *Shantung*?)" Another note in red ink at the end of the collection reads—"These books were read once in the lucky month of the sixth year of the *Tao-kuang* reign, by *Ch'io-li-tzŭ* in the library of *T'ung Yin* 桐蔭 (Shadow of tung-oil tree), Tortoise Mountain, Terrace of *Hsien* 仙, *Li-nan*. The price of the books was one hundred and sixty *liang* of silver official weight." (0.72 *liang* = 1 Chinese dollar; 12 *liang* = 1 pound weight.) We are not able to reconcile the two notes unless it be by supposing that *Ch'io-li-tzŭ* purchased the books in 1818, read and punctuated them in 1826, and sold them in the same year to a fellow-citizen of *Li-nan* at a considerable profit.

* Within the square brackets references are given to the corresponding sections of the *Tao tsang* 道藏 and the *Tao tsang chi yao* 道藏輯要.

[3] By pages we here mean the double pages of the Chinese printing style.

2.) Efficacy in using medicines and materials, 2¾ pages.

3.) Efficacy in using the *ting* 鼎 (furnace, tripod) and the apparatus, 2¼ pages.

4.) Efficacy in collecting and in selecting, 6½ pages.

5.) Efficacy in using true earth, 2¼ pages.

6.) Efficacy in the fire and the season (tempering), 3 pages.

7.) Efficacy in using *huan tan* 還丹 (returned medicine), 1½ pages.

8.) Efficacy in applying topsy-turvy-ness, 2¼ pages.

9.) Efficacy in *shên hsien* 神仙 (immortality), 1½ pages.

Chüan 4.

1.) The use of fire and amulets, 1½ pages.

2.) The hours of the waned moon, the full moon, and the upper and lower quarter moons, 2¼ pages.

3.) Bewaring of danger and protecting from loss, 2¼ pages.

4.) Punishment and favor of the hours of *mao* 卯 and *yu* 酉, 1 page.

5.) Washing the body and hands for carefulness, 2 pages.

6.) Emerging from the womb and changing the *ting*, ¼ page.

7.) Breeding and murdering, 2¼ pages.

8.) Seven things ought to be known, 5½ pages.

Chüan 5.

1.) Twenty five poems on *chin tan*, 2½ pages.

2.) A song on an idea, 2½ pages.

3.) A poem on the sword, ½ page.

4.) Fifty poems on hitting the eyes, 5 pages.

5.) Memoranda on the Book of *Tao tê*, 12 pages.

6.) Poems on the suspended womb *ting*, ½ page.

7.) Poems on the lie-down-moon furnace, ¾ page.

8.) Poems on surrendering the dragon, ¾ page.

9.) Poems on surrendering the tiger, ¾ page.

10.) Poems on the stick, ¾ page.

11.) For *Ting-yang-tzŭ* 定陽子 (prose discussion), 1¼ pages.

Chüan 6.

Records on Life, 21 prose pieces written for 21 friends, discussing extensively the subject of *chin tan*. There are many references to mercury and lead, *yin* 陰 and *yang* 陽, dragon and tiger, etc., etc., 59 pages.

Chüan 7. (Conversations with disciples.)

1.) Life and death are important business, 2 pages.

2.) Favors from the sages, 1¼ pages.

3.) The size of the universe, 1¾ pages.

4.) *Tao* is originally *yin* and *yang*, 1¾ pages.

5.) *Chin i huan tan* 金液還丹 (Gold fluid returned medicine), 7 pages.

6.) Longevity of *hsien* and of Buddhas, 1½ pages.

7.) *Tao* is not manifested by words, 1½ pages.

8.) Stay or go, coming out from the womb, 2¼ pages.

9.) The three religions belong to one, 2¾ pages.

10.) All common people can acquire *Tao*, 2¼ pages.

11.) Acquiring *Tao* by looking at water, 2¾ pages.

12.) He who knows *hsing* 性 (character) becomes Buddha, 2½ pages.

Chüan 8.

1.) Pictures and Diagrams (diagrams and symbols for the origin), 13¾ pages.

2.) A list of representative *hsien*, 2½ pages.

3.) Miscellaneous, 7 pages.

4.) The source and history of *hsien*, with short biographies and 15 portraits of ancestor-*hsien* (more or less religious), 10 pages.

Chüan 9.

1.) A prose piece for *Wang Hsiang* 王祥, 4 pages.

2.) General remarks, 7½ pages.

Chüan 10.

Acquiring *Tao* by seeing *hsing* (character), 10¾ pages.

II. *Lung hu shang ching* 龍虎上經 (Sacred Book of Dragon and Tiger), anonymous, with commentaries by *Wang Tao* 王道, 3 *chüan* in 1 volume. The text is divided into short paragraphs, each of which is accompanied by brief statements by the commentator; the resulting chapters are headed as follows. [*Tao Tsang*, 620; '*yao*. 斗 4.]

Chüan 1.

1.) Preface by *Wang Tao*, 2 pages.

2.) Preface by *Chou Chên-i* 周眞一, ¾ page.

3.) The key of *tan* 丹 is *shên shih* 神室 (efficacious chamber), 1½ pages.

4.) Coming from *yang* and entering into *yin*, 2¼ pages.

5.) Controlling the controller, 1½ pages.

6.) *K'an* 坎 and *li* 離 counting one and two, 1½ pages.

7.) Hardness and softness contain inside and outside, 1½ pages.

8.) Changes which are not yet efficacious, 1½ pages.

9.) Water and fire locate separately, 1½ pages.

10.) Setting up a seat in the efficacious chamber, 2 pages.

11.) Inter-control of existing and non-existing, 1½ pages.

12.) The instructions tell no lies, 2¼ pages.

13.) Gold-fire is lead, 3½ pages.

14.) With shining luster, 2 pages.

15.) The mysterious lady demonstrates her program, 1 page.

Chüan 2.

16.) Wish for compounding, 2¾ pages.

17.) *Shên* (appearance) changes into *chên* 震 (☳), 1½ pages.

18.) Sixteen changes are mutually subtracted, 2 pages.

19.) *Ch'ien* 乾 (☰) (heaven) and *k'un* 坤 (☷) (earth) include the beginning and the end, 1¾ pages.

20.) Sixty days of regulating the fire, 1¼ pages.

21.) At the beginning the fire should be gentle, 2 pages.

Chüan 3.

22.) Applying first to the efficacious chamber, 1 page.

23.) *Ch'i* (ethereal essence) of *yang* originates from *k'un*, 1 page.

24.) The star gods arrive from above, 1 page.

25.) Fire compounds in the earth of the central chamber, 1½ pages.

26.) Earth stabilizes the central chamber, 2 pages.

27.) Water and earth marry one another, 1 page.

28.) Golden virtues plus lead-compounding, 1 page.

29.) Existing and non-existing control each other, ¾ page.

30.) Compound silver out of lead, 2 pages.

31.) Silver is the mother of lead, 1½ pages.

32.) Shell is the essence of gold, 1 page.

33.) The round body rises up at the center, 1½ pages.

34.) The magnet attracts iron, 1 page.

35.) Nothing untrue in the Record of Fire, 1¾ pages.

36.) Diagram of the fire and the season, 1 page.

37.) Diagram of raw medicine, 1 page.

38.) Notes by *Wang Tao*, 2¾ pages.

This completes the first package.

III. *Chou i ts'an t'ung ch'i* 周易參同契 (The Akinness of the Trio, based on the Book of Change of the *Chou* 周 dynasty) (by *Wei Po-yang* 魏伯陽), with commentaries by *Chên-i-tzŭ* 眞一子, *P'êng Hsiao* 彭曉 of *Fei-hao-shan* 飛鶴山 (Flying Crane Mountain), 3 *chüan* in 2 volumes, 72 pages. [*Tao Tsang*, 623.]

In this version the *Ts'an t'ung ch'i* is divided into 90 chapters and additional miscellaneous sentences, with long commentaries on each chapter. A picture of the *wu* 烏 (crow), symbolizing the sun, a picture of the *t'u* 兎 (rabbit) symbolizing the moon, and a diagram, "Analysis of the meanings of the *kua* 卦," are included. There is a preface by the commentator, undated, 3 pages, and a note at the end, 2 pages, dated the tenth year of the reign of *Kuang-chêng* 廣正 of the kingdom of *Shu* 蜀 (*Ssŭ-ch'uan* 四川).

IV. *Chou i ts'an t'ung ch'i* with commentaries by *Pao-i-tzŭ* 抱一子, *Ch'ên Hsien-wei* 陳顯微, 3 *chüan* in 1 volume, 63 pages. [*Tao Tsang*, 628; °*yao* 虛 4.]

The *Ts'an t'ung ch'i* is here divided into three principal parts and additional miscellaneous sentences. Each of the three parts is further subdivided into paragraphs to which commentaries are attached. There are two prefaces, one by *Chêng Po-ch'ien* 鄭伯謙, 1½ pages, and one by the commentator, *Pao-i-tzŭ*, 2½ pages; both are dated in the same year but two months apart, namely the first year of the reign (1234–1237) of *Tuan-p'ing* 端平 of the *Sung* 宋 dynasty. Two notes, 2 pages, by two of the commentator's disciples, one anonymous, the other by *Wang I* 王夷, dated in the same year as the master's preface, are printed at the end of the treatise.

V. *Chou i ts'an t'ung ch'i*, written by *Wei Po-yang* 魏伯陽 of *Kuei-chi* 會稽 and commented upon by *Shang-yang-tzŭ* of *Lu-ling* 廬陵, 3 *chüan* in 2 volumes, 100 pages.

The text is here reorganized into 35 chapters and additional miscellaneous sentences. Each chapter is given a title and equipped with a lengthy commentary. There is neither preface nor appended note, and no date for the commentary is indicated.

VI. *Hsüan hsüeh chêng tsung* 玄學正宗, (Real Literature of *hsüan* (mystery)), 2 *chüan*, about ¾ of a volume. Two parts, without preface or date.

Part 1. *I wai pieh chuan* 易外別傳 (Some Outer Stories, based on the Book of Change), written by *Yü Shih-chien* 俞石澗, 39 pages. Discussions, notes and quotations, chiefly in explanation of mercury, lead, dragon, tiger, etc. [*Tao Tsang*, 629.]

Part 2. This consists of three pieces either written or commented upon by *Yü Yen* 俞琰 or *Lin-wu shan jên* 林屋山人 (Forest House

Mountain Fellow), identified with *Yü Shih-chien* of the *Yüan* 元 dynasty, as follows.

1.) A Song on *hsüan p'in* 玄牝 (mysterious female), 1½ pages.

2.) A Poem on *tan* 丹 by *Lü Tung-pin* 呂洞賓 (irregular verse) with commentaries by *Yü Yen*, 7 pages.

3.) Book of *Yin-fu* 陰符 (Amulets of *yin*), anonymous, with commentaries by *Yü Yen*, 9 pages. Discusses breeding and murder, conduct and virtue, etc.

VII. *Tan shu* 丹書 (Papers on *tan*), 1 *chüan*, 15 pages or about ¼ volume. Two pieces, both published anonymously with anonymous commentaries.

1.) *Chin tan ssŭ pai tzŭ* 金丹四百字 (Four Hundred Word *chin tan*) anonymous (by *Chang Po-tuan* 張伯端), with anonymous commentaries, 9 pages. [*Tao Tsang*, 122.]

2.) *Chin ku ko* 金穀歌 (Song on the Golden Millet), anonymous, with anonymous commentaries, 6 pages.

This completes the second package.

VIII. *Wu chên p'ien* 悟眞篇 (Essay on the Understanding of the Truth) by *Chang Po-tuan*, with prefaces and commentaries, 2 *chüan*, 2 volumes, 114 pages. [*Tao Tsang*, 126–127.]

1.) Preface of *Tai Ch'i-tsung* 戴起宗 (*K'ung-hsüan-tzŭ* 空玄子) (Empty Mystery Fellow) of *Chi-ch'ing-lu* 集慶路) dated the first year of the *Chih-yüan* 至元 reign (1335–1341), 2¾ pages.[4]

2.) Preface of *Ch'ên Ta-ling* 陳達靈, with additional notes, undated, 2¼ pages.

3.) Preface of *Wêng Pao-kuang* 翁葆光, written in the year *kuei ssŭ* 癸巳 of the *Ch'ien-tao* 乾道 reign (1165–1174) of the *Sung* dynasty in the fifteenth day of autumn by *Wêng Pao-kuang*, *Wu-ming-tzŭ* 無名子 (No Name Fellow) of *Hsiang-ch'uan* 象川, with additional notes, 6¼ pages.

4.) Preface of *Chang Po-tuan*, written in the year *i mao* 乙卯 of the *Hsi-ning* 熙寧 reign (1068–1078) of the *Sung* dynasty by *Chang Po-tuan*, *P'ing-shu* of *T'ien-t'ai* 天台, 3½ pages.

5.) Text of the *Wu chên p'ien*, 99 poems, with commentaries, 99 pages.

IX and X. Materials supplementary to the *Wu chên p'ien*, 1 *chüan*, 1 volume, 41 pages. Everything in this volume is included under the title of *Wu chên p'ien*, but none of it is actually *Wu chên p'ien*. The first part of this appendix contains three songs which are evidently the work of *Chang Po-tuan*, for two of them are printed later in this same encyclopedia under his name. The second part appears to be a collection of material by *Wêng Pao-kuang* with additions by *Tai Ch'i-tsung*.

IX. Three Songs.

1.) Notes on Reading the *Chou i ts'an t'ung ch'i*, anonymous, a song with commentaries by *Wêng* and *Tai*. Text ¾ page, commentaries 5½ pages.

2.) A Song for *Liu* 劉, a Comrade of *Tao*, of the White Tiger Cave, anonymous. Text and commentaries by *Wêng* and *Tai*, 3½ pages.

3.) A Song about the Stone Bridge, anonymous. Text 1 page, commentaries by *Tai* ½ page.

X. *Chih chih hsiang shuo san ch'êng pi yao* 直指詳說三乘秘要 (Straight Guide and Full Explanation Leading to the Secret of the Third Degree) by *Wêng Pao-kuang*, 1 *chüan*, 29 pages. [*Tao Tsang*, 64; *yao* 奎 2.]

1.) Straight guide to understanding the truth, 5½ pages.

2.) Forcing the army to win the battle, ½ page.

3.) Enrich the country and pacify the people, 1½ pages.

4.) Holding only one principle to become *shên hsien* 神仙, 2 pages.

5.) Poems on the Secret of the third degree, with notes, 2 pages.

6.) Biography of *Chang, chên jên* 張眞人, 1¼ pages.

7.) Adventure of *Hsieh* 薛 *Tzŭ-hsien* 紫賢 (*Hsieh Tao-kuang* 薛道光), anonymous, 2½ pages.

8.) Arguments on *Wu chên p'ien* by *Tai Ch'i-tsung*, 3½ pages.

9.) Notes on *Wu chên p'ien* by *Tai Ch'i-tsung*, 1 page.

10.) A table by *Tai Ch'i-tsung*, about 600 terms arranged under the headings, a.) *yang* 陽, b.) *yin* 陰, c.) *yin* inside *yang*, d.) *yang* inside *yin*, e.) neutral bodies (matchmaker ?), f.) external medicines, and g.) internal medicines, 7½ pages.

XI to XIX. *Chu chên hsüan ao chi* 諸眞玄奥集 (Collection of Papers on Mysteries and Wonders of Various True Men), 9 *chüan*, 6 volumes.

XI. Four Hundred Word *chin tan* by *Tzŭ-yang* 紫陽, *chên jên*, text and commentaries of *Huang Tzŭ-ju* 黄自如, 1 *chüan*, 10½ pages. [*Tao Tsang*, 741; *Yao* 奎 2.]

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[4] Concerning the authenticity of the commentaries of *Tai Ch'i-tsung* and *Wêng Pao-kuang*, see *Proc. Amer. Acad. Arts and Sciences*, *73*, 101 (1939).

1.) *Huang*'s preface, dated the first year of the *Shun-yu* 淳祐 reign (1241–1253), ¾ page.

2.) Preface of *Tzŭ-yang, chên jên*, undated, believed to be spurious, 3¼ pages.

3.) Text, 20 poems of 20 characters each, with very brief commentaries, 5 pages.

4.) Five Poems of *Huang Tzŭ-ju*, 1¼ pages.

XII. Essay on Returning to the Origin by *Shih Hsing-lin* 石杏林.

1.) Preface of *Shih Hsing-lin*, ½ page.

2.) Text, 81 short poems, 8¼ pages.

3.) Notes by the author, ¾ page.

XIII. Essay on the Returned Medicine for Fulfilling the Will of Heaven by *Hsieh Tao-kuang*, 1 *chüan*, 14½ pages.

1.) Author's preface, dated the year *ping wu* 丙午 of the *Ching-k'ang* 靖康 reign (1126–1127) of the Sung dynasty, 1½ pages.

2.) Text, 55 poems, 9¼ pages.

3.) Song on the Marrow of *tan*, 34 stanzas, 3¾ pages.

XIV. *Ts'ui hsü p'ien* 翠虚篇 (Essay on Green Emptiness) by *Ch'ên Nan* 陳楠, 1 *chüan*, 22 pages. [*Tao Tsang*, 742; ‘*Yao* 奎 4.]

1.) Preface of *Wang Ssŭ-ch'êng* 王思誠 (a disciple ?), undated, 1 page.

2.) Book of the Yellow Court, 2¾ pages.

3.) Theory of the single basis of *tan*, 2¼ pages.

4.) 103 miscellaneous poems on *chin tan*, 16 pages.

XV. *Chin i huan tan yin chêng t'u* 金液還丹印証圖 (Tested Pictorial Representations of *chin i huan tan*), with explanations, taught by *Pai Yü-ch'an* 白玉蟾 and drafted by *Lung-mei-tzŭ* 龍眉子; 20 pictures with a poem and explanation after each, 1 *chüan*. Preface by *Lung-mei-tzŭ*, dated in the year *Wu yin* 戊寅, reign of *Sung* 宋 *Chia-ting* 嘉定 (1208–1225), 2 pages. Pictures and explanations, 45 pages. [*Tao Tsang*, 68; ‘*Yao* 胃 11.]

XVI. *Chih hsüan p'ien* 指玄篇 (Guide to the Mystery) by *Pai Yü-ch'an*, 1 *chüan*, 47½ pages. [*Tao Tsang*, 122.]

1.) 20 diagrams with explanations, 10½ pages.

2.) Book of *wu* 烏 (crow) and *t'u* 兎 (rabbit), 1 page.

3.) Book of chains, 1½ pages.

4.) Rules of the *tan* laboratory, 1¼ pages.

5.) Essay on the addition in the eastern house, 1¼ pages.

6.) Essay on the addition (of medicine) on the winter solstice, 1¼ pages.

7.) Essay on persuading to *Tao*, ¾ page.

8.) Song on visiting the cloud, part 1, 1¾ pages.

9.) Song on visiting the cloud, part 2, 1¼ pages.

10.) 30 poems celebrating *Hua-yang* 華陽, 5 pages.

11.) 20 poems on lying with one's head on his upthrown arm, 3 pages.

12.) Miscellaneous poems and verses, 7½ pages.

13.) Thanking *Tzŭ-yang, chên jên* (prose), 3¾ pages.

14.) Miscellaneous prose pieces, 7 pages.

This completes the third package.

XVII. *Chin tan ta ch'êng chi* 金丹大成集 (Collection of Papers on *chin tan*), undated, by *Hsiao T'ing-chih* 蕭廷之, 1 *chüan*. [*Tao Tsang*, 123; ‘*Yao* 昴 4.]

1.) Magic diagrams of *tan* with explanations, etc., 8 pages.

a.) Diagram of limitlessness, with explanation, 1½ pages.

b.) Diagram of heaven's heart, ½ page.

c.) Diagram of *hsüan p'in* (mysterious female), ½ page.

d.) Diagram of already effective *ting* 鼎, ½ page.

e.) Diagram of *ho ch'ê* 河車 (river car), ½ page.

f.) Diagram of the heavenly fire and season cycle, ½ page.

g.) Diagram of fire and season disclosing heaven's amulets, 1½ pages.

h.) Diagram of fire and season of the 64 *kua* 卦, 1 page.

i.) Diagram of the magic numbers, 1 page.

j.) Diagram of the key-box of *chin tan*, ½ page.

2.) A Song on the key-box of *chin tan*, 1 page.

3.) Questions and answers on *chin tan*, 12½ pages.

4.) 81 short poems (on the same subject), 12½ pages.

5.) Several miscellaneous poems and songs, 6 pages.

6.) The Mirror of Qualified Medicines of *Ts'ui* 崔 with commentaries by *Hsiao T'ing-chih*, 7¾ pages.

7.) A poem (irregular verse) of *Lü* 呂 with commentaries by *Hsiao T'ing-chih*, 7 pages.

XVIII. *Hsien fo t'ung yüan lun* 仙佛同源論 (Hsien and Buddha are of the Same Origin), by *Chao Yu-ch'in* 趙友欽, undated, 1 *chüan*.

1.) Preface of *Shang-yang-tzŭ*, undated, 1½ pages.

2.) Preface of *Sun Pi* 孫碧 dated the year of *ting ch'ou* 丁丑 of the *Chih-yüan* 至元 reign (1335–1341), the fifteenth day of autumn, ¾ page.

3.) Preface of the author, undated, ¾ page.

4.) Text, 13 prose pieces on 13 miscellaneous subjects, 50 pages. The author quotes many passages from Buddhist and Taoist writings, compares the philosophies, and emphasizes the unity of the doctrine. The work contains relatively little on mercury and lead.

XIX. *Shih han chi* 石函記 (Story of the Stone Box) by *Hsü Chên-chün* 許眞君, 1 *chüan*. [*Tao Tsang*, 601; *'Yao* 危 3.]

1.) Notes (by the editor ?) ¾ page, state that in the second year of the *Ning-k'ang* 寧康 reign (373–376), the first day of the eighth month, *Hsü Chên-chün*, the author, left in *Hung-chou* 洪州, *Shan-hsi* 山西 Province, a stone box within which nine secret papers were sealed. The stone box was later found by *Chang Shou-fa* 張守發, 34 pages.

2.) The Original (Primary) Essence of the Sun, 4½ pages.

3.) The Sun and Moon, male and female, 2¼ pages.

4.) The mother of medicines, 4¾ pages.

5.) The right and the not-right medicines, 2¼ pages.

6.) A Song on proving *Tao* by *tan sha* 丹砂 (cinnabar), 1 page.

7.) Essay on guiding to *hsüan* (mystery) from the sage stone, 2½ pages.

8.) The roundness and shininess of *shên shih* 神室 (mysterious chamber), 6½ pages.

9.) *Hsü wu* 虛無 (empty-nothing) of the golden *ting* 鼎, 4¼ pages.

10.) The correct virtue of the shining hall, 5¼ pages.

XX. *Ch'ün hsien chu yü chi* 羣仙珠玉集 (Pearls and Jades Collected from Various Immortals), a collection of short pieces in prose and in verse by various authorities on *tan*. The editor, whose name is not indicated, was a person of good taste, for the pieces which are included in the collection are masterpieces of literary craftsmanship. No preface, no date. 4 *chüan*, three volumes.

Chüan 1, 24 essays on *tan* by authors of the period from the *Sung* to the Ming dynasty.

1.) Essay on *chin tan*, anonymous, 2 pages. [*Tao Tsang*, 121.]

2.) Essay on *huan tan* by *Liu Hai-ch'an* 劉海蟾 1 page

3.) Essay on *chin tan* by *Li Hsien-chün* 李仙君 1 page.

4.) Essay on the Valley God, anonymous, ¾ page.

5.) Essay on Internal *tan*, anonymous, 1 page.

6.) Essay on the Dragon and the Tiger, by *Pai Yü-ch'an*, 2 pages.

7.) Essay on the Great Gold Fluid Returned Medicine, by *Pai Yü-ch'an*, 1¼ pages.

8.) Essay on the Gold Fluid Returned Medicine by *Hsiao T'ing-chih* , 1½ pages.

9.) Essay on the Good Heart, anonymous, 1 page.

10.) Essay on the Eight Righteousnesses of a Buddhist, by *Fêng Tsun-shih* 馮尊師, 1 page.

11.) Essay on the Simple Life, anonymous, 1 page.

12.) Essay on the All-True, by *Fêng Tsun-shih*, 1 page.

13.) Essay on Capturing the Mystery of the Returned Medicine, anonymous, 1 page. [*Tao Tsang*, 121.]

14.) Essay on Capturing the Mystery of the Single Origin, anonymous, 1 page. [*Tao Tsang*, 121.]

15.) Essay on Capturing the Mystery of *Tao* 道, anonymous, ¾ page. [*Tao Tsang*, 121.]

16.) Essay on Capturing the Mystery of the Dragon and the Tiger, anonymous, ¾ page. [*Tao Tsang*, 121.]

17.) Essay on Capturing the Mystery of the Autumn Stone, anonymous, 1 page. [*Tao Tsang*, 121.]

18.) Essay on Capturing the Mystery of *ho ch'ê* 河車 (river car), anonymous, 1 page. [*Tao Tsang*, 121.]

19.) Essay on Capturing the Mystery of the Five Elements, anonymous, ¾ page. [*Tao Tsang*, 121.]

20.) Essay on Capturing the Mystery of the Womb, anonymous, 1 page. [*Tao Tsang*, 121.]

21.) Essay on Capturing the Mystery of Stealing the Secret, anonymous, 1 page. [*Tao Tsang*, 121.]

22.) Essay on *hsing* 性 (character) by *Chi Chih-chên* 姬志眞, 1¼ pages.

23.) Essay on *hsin* 心 (heart) by *Chi Chih-chên*, 1 page.

24.) Essay on Respecting *Tao* by the *Sung* Emperor *Jên-tsung* 仁宗, 1 page.

Chüan 2. 17 articles on *tan*, chiefly by authors of the *Ming* dynasty.

1.) The Nine Changes of Jade *tan*, anonymous, 4 pages.

2.) The First Chapter on *huan tan* by *T'ao Ch'ih* 陶埴, 2½ pages.

3.) The Second Chapter on *huan tan* by *T'ao Ch'ih* 1½ pages.

4.) The Last Chapter on *huan tan* by *T'ao Ch'ih*, 1½ pages.

5.) The Basis of *tan* Goes Back to the Single Origin, anonymous, 2¼ pages.

6.) Clearing the Way for Learning *hsien* by *Pai Yü-ch'an*, 3½ pages. [*Tao Tsang*, 122.]

7.) The Valley God Will Not Die, anonymous, 1½ pages. [*Tao Tsang*, 122.]

8.) The Increase and Decrease of *yin* 陰 and *yang* 陽, anonymous, 1 page. [*Tao Tsang*, 122.]

9.) The Gate of *hsüan* 玄 (mystery) Throws Light on the Secret, anonymous, 4¾ pages.

10.) *Chin tan* Creates Tinyness by *Wang Ching-yang* 王景陽, 2¼ pages.

11.) Gold Fluid Returned Medicine by *Hsiao T'ing-chih*, 2½ pages.

12.) The Secret of *hsüan*, anonymous, 2 pages.

13.) Reenforcement of *ch'i* and Recovery of *shên* (appearance, energy), anonymous, 1½ pages.

14.) The Two *ch'i* Produce *huang ya* 黃芽 (yellow sprout), by *Huan-yang-tzŭ* 還陽子, ½ page.

15.) The Recognition of Lead and Mercury, by *Huan-yang-tzŭ*, 1 page.

16.) Oral Instructions for *huan tan*, by *Ch'êng* 程, ½ page.

17.) The Skillfulness of the Dragon and the Tiger, anonymous, 2½ pages.

Chüan 3. 66 songs on *tan* by various authors.

1.) A Song on Loving *hsien* When One is Drunk, by *Hsü Chên-chün* 許眞君, 2 pages.

2.) A Song on the Great *huan tan*, by *Wu Chên-chün* 吳眞君, 1 page.

3.) A Song on Lead and Mercury, by *Yen Chün-p'ing* 嚴君平, ½ page.

4.) A Song on the Dragon and the Tiger, by *Ch'ang-shêng-yin chên jên*, 長生陰眞人, ½ page.

5.) A Song on Clarifying Perplexity and Returning to Real *Tao*, by *Chung-li Ch'üan* 鍾離權, ½ page.

6.) A Song on *huan tan*, by *Chung-li Ch'üan*, ½ page.

7.) A Song for *Tung-pin* 洞賓 on the Secret of *tan*, by *Chung-li Ch'üan*, ½ page.[5]

8.) A Song on Striking *yao* 爻 (the lines which compose the *kua* 卦), by *Lü Tung-pin*, 3½ pages.

9.) A Song on the Unburnt Bricks in the Pit, by *Lü Tung-pin*, 呂洞賓, 1½ pages.

10.) For the Scholar *Liu Fang* 劉方, a song by *Lü Tung-pin*, 1 page.

11.) Composed for the Shrine at the Gate of *Huang*'s 黃 Monastery on Cypress Mountain, a song by *Lü Tung-pin*, ½ page.

12.) For *Ch'iao-êrh-lang* 喬二郎, a song by *Lü Tung-pin*, ½ page.

13.) A Song on Apprehending *tao* on an Island in the River, by *Lü Tung-pin*, ½ page.

14.) A Song on the Valley God, by *Lü Tung-pin*, ½ page.

15.) A Song on the Strict Guide to the Great *tan*, by *Lü Tung-pin*, ½ page.

16.) A Song on Clarifying the Perplexity of *huan tan*, by *Liu Hai-ch'an* 劉海蟾, 1 page.

17.) A Song on the Supreme Truth, by *Liu Hai-ch'an*, 2 pages.

18.) A Song about the Stone Bridge, by *Chang Tzŭ-yang* 張紫陽, 1 page.

19.) A song for *Liu*, a Comrade of *Tao*, of the white tiger cave, by *Chang Tzŭ-yang*, 1 page.

20.) A Song on the Oral Secret of *huan tan*, by *Ma Tzŭ-jan* 馬自然, 1¾ pages.

21.) A Song on Metal and Stone, by *Ma Tzŭ-jan*, ½ page.

22.) A Song on *chin tan*,* by *Kao Hsiang-hsien* 高象先, 4½ pages.

23.) A Song on *Ts'ui hsü* 翠虛 (green emptiness) of *Lo-fu* 羅浮 Mountain, by *Ch'ên Nan* 陳楠, 4½ pages.

24.) A Song on the Great *Tao*, by *Ch'ên Nan*, 2 pages.

25.) A Song on the *Tao* which Dwells in the Primary Axis, by *P'êng Hao-lin* 彭鶴林, 1 page.

26.) A Song for *Hu-êrh-lang* 胡二郎, by *Êrh-chu* 爾朱, *chên jên*, ½ page.

27.) A Song on Returning to the Chamber from the West Wood, by *Pai Yü-ch'an* 白玉蟾, ½ page.

28.) A Song on the Unity of Thousands of *fa* 法 (talismans), by *Pai Yü-ch'an*, 2½ pages.

29.) Eventually It Must Be like That, a song by *Pai Yü-ch'an*, 1 page.

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[5] Several centuries intervened between the alleged author, *Chung-li*, and the disciple, *Tung-pin*, for whom the poem is supposed to have been written. The authorship of the two interesting poems which are ascribed to *Chung-li* is doubtful.

* A portion of this song has been translated and published, "An Alchemical Poem by *Kao Hsiang-hsien*," *Isis*, *30*, 236–240 (1939). The translation is of the portion quoted by *Tai Ch'i-tsung* in his commentaries on the *Wu chên p'ien*. At the time of reading the proof of that translation, we were not aware of the existence of this longer poem which we discovered while preparing the present Table of Contents.

30.) A Song on Contentment with One's Lot, by *Pai Yü-ch'an,* 1¼ pages.

31.) A Song on the Great Joy, part 1, by *Pai Yü-ch'an,* 3 pages.

32.) A Song on the Great Joy, part 2, by *Pai Yü-ch'an,* 1¼ pages.

33. A Song on the Great *Tao,* by *Pai Yü-ch'an,* 2 pages.

34.) A Song on the Grand Emptiness, by *Ma* 馬 *chên jên* of *Tan-yang* 丹陽, 1 page.

35.) A Song on the Evaluation of Gratifications, by *Ma chên jên* of *Tan-yang,* ¼ page.

36.) A Song on Going to the Court of *Yang,* by *Wang* 王 *chên jên* of *Yü-yang* 玉陽, ½ page.

37.) A Song on Meeting the Truth, by *Wang, chên jên* of *Yü-yang,* ½ page.

38.) A Song on the Mysterious Pearl, by *T'an Ch'u-tuan* 譚處端, ½ page.

39.) A Song on the Skeleton, by *T'an Ch'u-tuan,* ¼ page.

40.) A Song on Poverty, by *T'an Ch'u-tuan,* 1 page.

41.) A Song on the Summons to Retire, by *Chi* 姬 *chên jên* of *Chih-ch'ang* 知常, ½ page.

42.) A Song on Meeting True Men, by the scholar *Sung* 宋, ½ page.

43.) A Song on Solving Perplexity, by the scholar *Sung,* ¼ page.

44.) A Song on Receiving *Tao,* by *Wang Ching-yang* 王景陽, 1 page.

45.) A Song on the Lives of the Ancient *shên hsien,* by *Yüan-yang-tzŭ* 元陽子, 3¾ pages.

46.) A Song on the Green Dragon, by *T'ien-lai-tzŭ* 天來子, 2½ pages.

47.) A Song on the White Tiger, by *T'ien-lai-tzŭ,* 1½ pages.

48.) A Song on the Key-Box, by *Hsiao T'ing-chih* 蕭廷之, ¾ page.

49.) A Song on Enjoying *Tao,* by *Hsiao T'ing-chih,* 1¼ pages.

50.) A Song on Self Contentment in a Straw House, by *Hsiao T'ing-chih,* 1½ pages.

51.) A Song on the Sword, by *Hsiao T'ing-chih,* ¾ page.

52.) A Song on Apprehending Fatigue, by *Li* 李 *chên jên, T'ung-hsüan-tzŭ* 通玄子, ½ page.

53.) A Song on the Disgrace of the Village, by *Li chên jên, T'ung-hsüan-tzŭ,* ¾ page.

54.) A Song of Complaint at his Failure to Recognize *hsing* 性 (nature of man) and *ming* 命 (life, will of god), by *T'ung-hsüan-tzŭ,* ½ page.

55.) A Song on Compounding the Medicine Pointing to the Truth, by *Wang Ch'ing-shêng* 王慶升, ¾ page.

56.) There is No Need to Slay the Three Corpses, a song by *Wang Ch'ing-shêng,* ½ page.

57.) A Song on the Lead and Mercury of *chin tan,* anonymous, 1½ pages.

58.) A Song for *Ma* 馬, the Scholar, by *Niu Chia* 牛頰, 1¾ pages.

59.) A Song on the Secret of the Fire and the Season of *chin tan,* by *T'ai-shang-lao-chün* 太上老君, ¼ page.

60.) A Song on Understanding the Truth, anonymous, ¾ page.

61.) A Song on *huang ya* (yellow sprout), anonymous, ½ page.

62.) A Song on Proving *Tao,* anonymous, ¼ page.

63.) A Song on *shên tan* 神丹 (efficacious medicine), by *Lo Kung-yüan* 羅公遠, *chên jên,* ¾ page.

64.) A Song on the Treasure Chamber of *Min* 岷 Mountain, by *Ts'ui Hsüan-chên* 崔玄眞, 1 page.

65.) A Song on the Four Signs, by *Ts'ao* 曹 *chên jên,* ¾ page.

66.) A Song on Resolving Doubts, by *Shang-yang-tzŭ,* 2½ pages.

Chüan 4. Two papers which purport to have been enlarged by *Ch'ing-hsü-tzu* 淸虛子 *I-chên Yeh-jung* 頤貞埜容, but no evidence of the enlargement is apparent.

1.) Preface by *Ch'ien Tao-hua* 錢道華, 2 pages, dated the eighth year of the *Chêng-t'ung* 正統 reign (1436–1450).

2.) A Song on Striking *yao* 爻 (the lines which compose the *kua*), by *Lü Tung-pin* 呂洞賓 with commentaries by *Ch'ien Tao-hua,* 23 pages.

3.) A Guest from the Sea, anonymous, without commentary, a prose piece telling the story of an adventure relating to *chin tan,* 18 pages.

The encyclopedia includes writings by forty-six authors of whom six are also commentators, and of thirteen commentators who are represented only by their commentaries. An index of the writers follows.

Ch'an T'ien-tsung 蟾天宗 Commentator. I., sec. 1.
Chang Po-tuan 張伯端 Author. VII., sec. 1.; VIII.; IX.; XI., sec. 2, 3.; XX., *chüan* 3, sec. 18, 19.
Ch'ang-shêng-yin-chên-jên 長生陰眞人 Author. XX., *chüan* 3, sec. 4.
Chao Yu-ch'in 趙友欽 Author. XVIII.
Chên-i-tzŭ 眞一子 Commentator. III.
Ch'ên Hsien-wei 陳顯微 See *Pao-i-tzŭ.*
Ch'ên Kuan-wu 陳觀吾 See *Shang-yang-tzŭ.*

Ch'ên Nan 陳楠 Author. XIV.; XX., *chüan* 3, sec. 23, 24.
Ch'ên Ta-ling 陳達靈 Commentator. VIII., sec. 2.
Ch'êng 程 Author. XX., *chüan* 2, sec. 16.
Chêng Po-ch'ien 鄭伯謙 Commentator. IV.
Chi 姬 Author. XX., *chüan* 3, sec. 41.
Chi Chih-chên 姬志眞 Author. XX., *chüan* 1, sec. 22, 23.
Ch'ien Tao-hua 錢道華 Commentator. XX., *chüan* 4, sec. 1, 2.
Chih-hsü 致虛 See *Shang-yang-tzŭ*.
Chou Chên-i 周眞一 Commentator. II., sec. 2.
Chung-li Ch'üan 鍾離權 Author. XX., *chüan* 3, sec. 5, 6, 7.
Fêng Tsun-shih 馮尊師 Author. XX., *chüan* 1, sec. 10, 12.
Hsiao T'ing-chih 蕭廷之 Author. XVII., sec. 1, 2, 3, 4, 5.; XX., *chüan* 1, sec. 8.; XX., *chüan* 2, sec. 11.; XX., *chüan* 3, sec. 48, 49, 50, 51. Commentator. XVII., sec. 6, 7.
Hsieh Tao-kuang 薛道光 Author. XIII.
Hsü Chên-chün 許眞君 Author. XIX., XX., *chüan* 3, sec. 1.
Hu-êrh-lang 胡二郎 Author. XX., *chüan* 3, sec. 26.
Huan-yang-tzŭ 還陽子 Author. XX., *chüan* 2, sec. 14, 15.
Huang Tzŭ-ju 黃自如 Author. XI., sec. 4. Commentator. XI., sec. 1, 3.
Jên-tsung 仁宗 (*Sung* Emperor). Author. XX., *chüan* 1, sec. 24.
Kao Hsiang-hsien 高象先 Author. XX., *chüan* 3, sec. 22.
K'ung-hsüan-tzŭ 空玄子 See *Tai Ch'i-tsung*.
Li 李 See *T'ung-hsüan-tzŭ*.
Li Hsien-chün 李仙君 Author. XX., *chüan* 1, sec. 3.
Lin-wu shan jên 林屋山人 See *Yü Shih-chien*.
Liu Hai-ch'an 劉海蟾 Author. XX., *chüan* 1, sec. 2.; XX., *chüan* 3, sec. 16, 17.
Lo Kung-yüan 羅公遠 Author. XX., *chüan* 3, sec. 63.
Lü Tung-pin 呂洞賓 Author. VI., part 2., sec. 2.; XVII., sec. 7.; XX., *chüan* 3, sec. 8, 9, 10, 11, 12, 13, 14, 15.; XX., *chüan* 4, sec. 2.
Lung-mei-tzŭ 龍眉子 Commentator. XV.
Ma Tzŭ-jan 馬自然 Author. XX., *chüan* 3, sec. 20, 21, 34, 35.
Niu Chia 牛頰 Author. XX., *chüan* 3, sec. 58.
Ou-yang T'ien-ch'ou 歐陽天疇 Commentator. I., sec. 2.
Pai Yü-ch'an 白玉蟾 Author. XV.; XVI.; XX., *chüan* 1, sec. 6, 7.; XX., *chüan* 2, sec. 6, 27, 28, 29, 30, 31, 32, 33.
Pao-i-tzŭ 抱一子 Commentator. IV.
P'êng Hao-lin 彭鶴林 Author. XX., *chüan* 3, sec. 25.
P'êng Hsiao 彭曉 See *Chên-i-tzŭ*.
P'ing-shu 平叔 See *Chang Po-tuan*.
Shang-yang-tzŭ 上陽子 Author. I.; XX., *chüan* 3, sec. 66. Commentator. V.; XVIII., sec. 1.
Shih Hsing-lin 石杏林 Author. XII.
Sun Pi 孫碧 Commentator. XVIII., sec. 2.
Sung 宋 (the scholar). Author. XX., *chüan* 3, sec. 42, 43.
Tai Ch'i-tsung 戴起宗 Author. X., sec. 8, 9, 10. Commentator. VIII., sec. 1.; IX., sec. 1, 2, 3.
T'ai-shang-lao-chün 太上老君 Author. XX., *chüan* 3, sec. 59.
T'an Ch'u-tuan 譚處端 Author. XX., *chüan* 3, sec. 38, 39, 40.
T'ao Ch'ih 陶埴 Author. XX., *chüan* 2, sec. 2, 3, 4.
T'ien-lai-tzŭ 天來子 Author. XX., *chüan* 3, sec. 46, 47.
Ts'ao 曹 Author. XX., *chüan* 3, sec. 65.
Ts'ui 崔 Author. XVII., sec. 6.
Ts'ui Hsüan-chên 崔玄眞 Author. XX., *chüan* 3, sec. 64.
T'ung-hsüan-tzŭ 通玄子 Author. XX., *chüan* 3, sec. 52, 53, 54.
Tzŭ-yang 紫陽 See *Chang Po-tuan*.
Wang 王 *chên jên* of *Yü-yang* 玉陽 Author. XX., *chüan* 3, sec. 36, 37.
Wang Ching-yang 王景陽 Author. XX., *chüan* 2, sec. 10.; XX., *chüan* 3, sec. 44.
Wang Ch'ing-shêng 王慶升 Author. XX., *chüan* 3, sec. 55, 56.
Wang I 王夷 Commentator. IV.
Wang Ssŭ-ch'êng 王思誠 Commentator. XIV., sec. 1.
Wang Tao 王道 Commentator. II., sec. 1.
Wei Po-yang 魏伯陽 Author. III.; IV.; V.
Wêng Pao-kuang 翁葆光 Author. X., sec. 1, 2, 3, 4, 5, 6, 7. Commentator. VIII., sec. 3.; IX., sec. 1, 2.
Wu Chên-chün 吳眞君 Author. XX., *chüan* 3, sec. 2.
Wu-ming-tzŭ 無名子 See *Wêng Pao-kuang*.
Yen Chün-p'ing 嚴君平 Author. XX., *chüan* 3, sec. 3.
Yü Shih-chien 俞石澗 Author. VI., part 1., part 2., sec. 1. Commentator. VI., part 2., sec. 3.
Yü Yen 俞琰 See *Yü Shih-chien*.
Yüan-yang-tzŭ 元陽子 Author. XX., *chüan* 3, sec. 45.

GYROMAGNETIC RATIOS FOR FERROMAGNETIC SUBSTANCES: NEW DETERMINATIONS AND A NEW DISCUSSION OF EARLIER DETERMINATIONS

By S. J. Barnett

Received August 1, 1938 Presented October 19, 1938

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Part I

INTRODUCTION AND REFERENCES

§ 1. Introduction. This paper is a sequel to three others published in these Proceedings in and before 1934, and referred to below as II, III and V. It is concerned chiefly with the latest stage of a long investigation which has passed through five distinct earlier stages as follows:

(1). 1914. The discovery of magnetization by rotation, or the Barnett effect, by a method of electromagnetic induction, and the measurement, with an error of only a few per cent, of the gyromagnetic ratio for iron, showing that it is approximately equal to m/e for a negative electron in slow translatory motion, and thus identifying Ampère's whirls as (at least chiefly) spinning negative electrons.

(2). 1915. The confirmation and refinement of the results of 1914 by means of improvements in the same method.

(3). 1917. Rough measurements by a magnetometer method showing that iron, nickel and cobalt all have gyromagnetic ratios of the same sign and of nearly the same magnitude.

(4). 1920–1925. A very elaborate and much more precise investigation, by magnetometer methods, of the same effect in many ferromagnetic substances, showing conclusively that the mean gyromagnetic ratio is several per cent greater than m/e and *apparently* differs for different ferromagnetic materials. The results thus indicated that while the spinning electron is the principal magnetic element the orbit also participates to a greater or less extent.

(5). 1927–1934. A long series of precise measurements of the gyromagnetic ratios of iron, permalloy, nickel, and cobalt by means of the converse effect, rotation by magnetization, or the Einstein and de Haas effect. These experiments confirmed in general the results of (4) on the same materials, increased the precision, and showed conclusively that the gyromagnetic ratio varies from material to material.

The objects of the present paper are as follows:

(1) To present an account of new measurements of the gyromagnetic ratios of many ferromagnetic substances by means of the Einstein and de Haas effect, or rotation by magnetization. For a number of the substances investigated this effect has not hitherto been studied, and it has been considered important to extend the work already done on the others. The paper has been somewhat slow in following its predecessors because the new work has required a vast amount of labor both on my own part and on the part of those who have assisted me.

(2) To present, as a result of such measurements, more precise evidence on the question of the location of the angular momentum produced in experiments of this kind.

(3) To revise slightly, in view of the new experiments on e/m and other work, the results obtained by L. J. H. Barnett and myself in our Washington work on magnetization by rotation.

(4) To present some hitherto unpublished, and comparatively rough, results in this field obtained by visitors to the laboratory, partly on account of their historical interest and partly because they show the possibilities of this method even in the daytime, under very adverse conditions.

(5) To compare and discuss so far as necessary the results obtained by the two different methods of research and by different investigators.

§ 2. REFERENCES TO EARLIER PAPERS. It will be conducive to brevity in this paper to refer to the more detailed articles in this field which have hitherto emanated from the author's laboratories by the numerals which are affixed to the titles in the following list:

I. Magnetization by rotation. Phys. Review **6**: 239–270, 1915.

II. New researches on the magnetization of ferromagnetic substances by rotation and the nature of the elementary magnet. (With L. J. H. Barnett.) Proc. Amer. Acad. **60**: 127–216, 1925.

III. Researches on the rotation of permalloy and soft iron by magnetization and the nature of the elementary magnet. Proc. Amer. Acad. **66**: 273–348, 1931.

IV. A new electron inertia effect and the determination of m/e for the free electrons in copper. Phil. Mag. **12**: 349–360, 1931.

V. The rotation of cobalt and nickel by magnetization and the gyromagnetic ratios of their magnetic elements. Proc. Amer. Acad. **69**: 119–135, 1934.

VI. Gyromagnetic and electron-inertia effects. Reviews Modern Phys. **7**: 129–166, 1935.

PART II. WORK ON ROTATION BY MAGNETIZATION

A. GENERAL EXPERIMENTAL METHODS AND EXAMPLES

§ 3. EXPERIMENTAL METHODS, APPARATUS, AND ERRORS IN THE NEW WORK. All the work undertaken since that published in V has been done by three of the general resonance methods described in III, V, and VI. Reference must be made to these papers for most of the experimental details and for discussions of most of the numerous errors which have to be avoided or eliminated. Modifications adopted in the methods and in the apparatus, and some additional sources of error, will be discussed in appropriate places below.

In most of the work described in III and V the magnetizing coil was wound rigidly on the rotor. In much, perhaps most, of the new work, the magnetizing coil has been fixed to the suspension supports. A diagram of the chief experimental circuits is given for this case in Fig. 1. C is the rotor proper, D the magnet-mirror holder, E the mirrors, F the permanent magnets. B and A are the fixed magnetizing and induction solenoids, and B'–A' their mutual inductance compensator. G and H are the torque and quadrature coils, and G'–H' their mutual inductance compensator. W is the commutator, U the asymmetry reversing switch, R the torque coil reversing switch, P and

S the quadrature coil switches, L and M the quadrature coil voltage dividers (about 18 ohms each) for the two positions of U and P, which are operated together, and QQ' the coils of high resistance in the quadrature coil circuit. The earth connections at Z and Y were not always made, neither was the connection between IJ and G' always made.

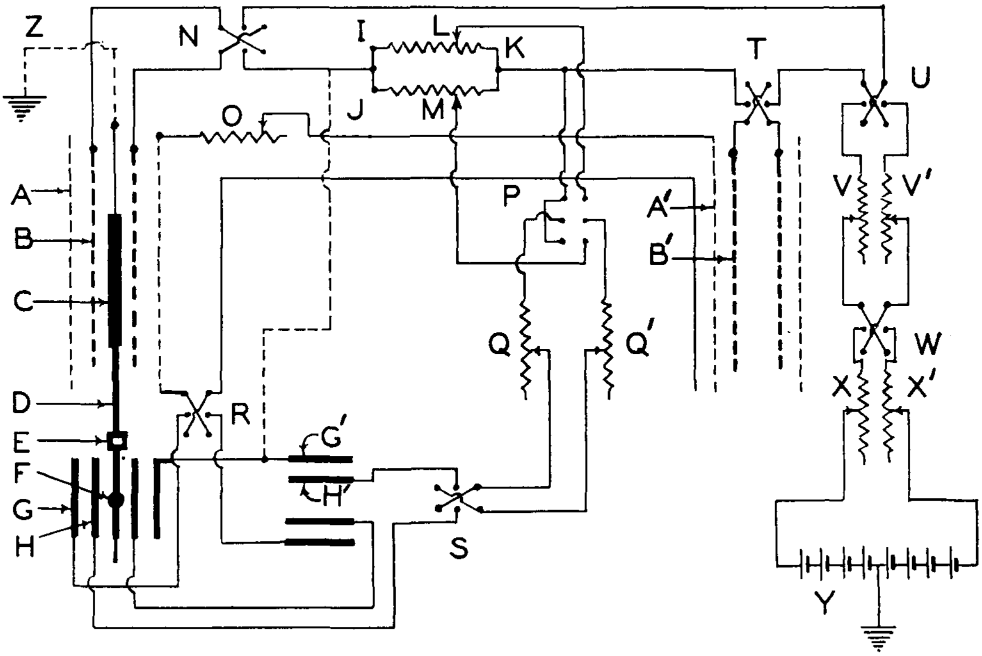

Figure 1. Diagram of the principal apparatus as arranged for work with the magnetizing coil fixed to the earth.

§ 4. Method I. Most of the observations have been made by the *Large deflection method II* of III § 26, which is identical with the *Large deflection method* (*a*) of VI §30, with the modifications indicated in the next paragraph (§5). In this method the conductance $X_0 + \delta X_0$ of the secondary circuit at which the resonance amplitude is a minimum is determined by measuring *accurately* the amplitudes A and A_2 (= approximately A), respectively, for $X = 0$ and $X = X_2$ = approximately $2(X_0 + \delta X_0)$; by measuring *approximately* the amplitude A_0, the approximate minimum amplitude, for X = approximately $X_0 + \delta X_0$; and by substituting in the formula

$$X_0 + \delta X_0 = \frac{(A^2 - A_0^2)^{1/2}}{(A^2 - A_0^2)^{1/2} + (A_2^2 - A_0^2)^{1/2}} \qquad (4\text{-}1)$$

X_0 is the conductance at which the amplitude would vanish if there were no extraneous torques; and δX_0, the error due to such torques, is eliminated by making observations for both directions, I and II, of the asymmetry reversing switch U in the magnetizing circuit, and for two azimuths, NPE and NPW, differing by 180°, of the rotor and permanent magnet attached to it. The mean value of δX_0 for these four arrangements is zero, and the gyromagnetic ratio is determined from the equation

$$-\rho = X_0 \Gamma_0 \gamma_0 m_0 \qquad (4\text{-}2)$$

where Γ_0 and γ_0 are the constants of the *torque coil* and *induction solenoid*, respectively, and m_0 is the moment of the permanent magnet. If the magnetizing coil is wound upon the rotor, small corrections must be applied for electron-inertia in the coil and for its magnetic moment.

In a comparatively small part of the new work the method was slightly modified in the manner described at the end of V §2, p. 123. In this modification $X_0 + \delta X_0$ was obtained by taking one-half the value of X for which the precisely measured amplitude (beyond the minimum) was *equal* to the amplitude (also measured with precision) for which $X = 0$. The first value was, as in V, not observed directly, but was obtained by interpolation or extrapolation for values of X

near $2(X_0 + \delta X_0)$; and $X_0 - \delta X_0$ was obtained in the same way. Repeated observations were made as in the unmodified method, an example of which is given in §5.

§ 5. EXAMPLE OF METHOD I. An example of Method I, as modified for nearly all of the work described here, is given in Table 1, which contains the amplitude observations on the long wound 2 mm. permalloy rotor made on January 14–15, 1935, and the results. The vibration observations began at 11:31 p. m. and ended at 2:50 a. m. The intensity of the magnetizing field was about 35 gausses, and the frequency 9.8 per second. The vertical intensity of the earth's field was doubled, instead of being annulled, as usually. The moment of the rotor was about 640 e.m.u. and that of its coil (traversed by a current of 0.1 ampere) about 4.5 e.m.u. The moment of the permanent magnet was 0.684 e.m.u.

Instead of making a single measurement of amplitude for each setting of the resistance and reversing switch, the measurements (in all methods used) have long been made in groups of 3, with an interval of half a minute between the first and second and second and third. This enables the observer to be certain that sufficient time has been allowed to elapse between the different settings. For each of the azimuths (1) and (2) two groups A and B of amplitude determinations are made, each group containing 24 separate measurements taken, as in the earlier work, on a strict time schedule. The numbers in parentheses under A and B give the order of the observations. Between (3) and (4), (9) and (10), (15) and (16), and (21) and (22), there is an interval of 2^m; between (6) and (7), (18) and (19), an interval of 3^m. Between the other successive numbers there is an interval of $\frac{1}{2}^m$. Except the last interval, which has almost always been kept the same, the intervals are not the same for all rotors, as they have very different time constants. For each of the azimuths (1) and (2), or north pole of the vibrator magnet east and north pole west, and each position of the reversing switch, I and II, the values of $\rho e/m$ are given, together with the final means, at the foot of the table. The result, 1.057, like the other values for this rotor in Series IV, Table 40–1, is greater than the mean for the other series, possibly because of the relatively intense vertical magnetic field in which the vibrations were made.

§ 6. METHOD II. This is the *Large deflection method I* of III § 20, and the *Large deflection method* (*c*) of VI § 30, B, with improvements. It was but little used in III, and was there incompletely described and discussed. In it a comparison is made between (1) the amplitude A_G of the vibration produced by the first harmonic of the gyromagnetic torque $g = G \cos \omega t$ when there is no current in the torque coil, and (2) the amplitude A_c of the vibration produced by the first harmonic of an independent current $c = C \cos (\omega t + \delta)$ in the torque coil when there is no gyromagnetic torque acting. The magnitude of the gyromagnetic ratio is given by the equation

$$|\rho| = (\Gamma_0 m_0 C/\omega\mu_0)\, A_G/A_c \tag{6-1}$$

where μ_0 is the amplitude of the first harmonic of the magnetic moment of the magnetic material in the rotor.

A considerable amount of time has been spent in developing this method, but in some of the work the precautions taken or the quadrature coil data (see § 32) have not been such as to justify the inclusion of the results here.

In practice the same reversals made in the first method are required to eliminate extraneous torques in phase with or in opposition to the gyromagnetic torque; also separate experiments must be made to test for and measure any quadrature torque present. If there is present a quadrature torque which alone would produce an amplitude A_0, the amplitude A_G in (1) would be found from the *measured* amplitude A by means of the relation $A_G = (A^2 - A_0^2)^{1/2}$.

If the magnetizing coil is wound rigidly on the magnetic material and has a moment whose amplitude is μ_0', it will give rise to a torque with amplitude $\rho'\omega\mu_0'$ which is in phase with the gyromagnetic torque with amplitude $\rho\omega\mu_0$ and alone would produce an amplitude A_E. Here ρ' is the ratio of the angular momentum of an electron moving in a circle to its magnetic moment, viz. $2\,m/e$ (see IV). The observed amplitude in case (1), corrected for any quadrature effect, will now be $A = A_G + A_E$, and we shall have

$$\frac{A(\equiv A_G + A_E)}{A_c} = \frac{\rho\omega\mu_0 + \rho'\omega\mu_0}{\Gamma_0 m_0 C}$$

or

$$\rho = \frac{\Gamma_0 m_0 C\, A}{\omega\mu_0\, A_c} \cdot \frac{1}{1 + \rho'\mu_0'/\rho\mu_0} \tag{6-2}$$

Since $\rho'/\rho \leqslant 2$, and $\mu_0'/\mu_0 << 1$, this equation becomes, with a sufficient degree of precision,

$$|\rho| = \frac{\Gamma_0 m_0 C\, A}{\omega\mu_0\, A_c}(1 - \rho'\mu_0'/\rho\mu_0) \tag{6-3}$$

TABLE 1

Observations on 2 mm. Wound Permalloy Rotor, January 15, 1935, and Results

I. 2 × amplitude in cm.

(1) North Pole East

Mean $2A_0$ I = 0.50† Mean $2A_0$ II = 0.20†

A

Resistance*	∞ I			2168.2 II			∞ II			2168.2 I		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	4.86	4.86	4.84	4.80	4.82	4.80	4.62	4.62	4.62	4.76	4.74	4.78
	(24)	(23)	(22)	(21)	(20)	(19)	(18)	(17)	(16)	(15)	(14)	(13)
	4.88	4.92	4.90	4.82	4.82	4.86	4.62	4.61	4.62	4.74	4.72	4.76

B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	4.92	4.90	4.90	4.92	4.94	4.92	4.62	4.62	4.60	4.86	4.86	4.84
	(24)	(23)	(22)	(21)	(20)	(19)	(18)	(17)	(16)	(15)	(14)	(13)
	4.86	4.86	4.90	4.90	4.88	4.90	4.64	4.64	4.62	4.82	4.84	4.82
Means	4.883			4.865			4.621			4.795		

(2) North Pole West

Mean $2A_0$ I = 0.20 Mean $2A_0$ II = 0.65

A

Resistance*	∞ I			2238.2 II			∞ II			2168.2 I		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	4.80	4.82	4.80	4.84	4.82	4.86	4.70	4.70	4.71	4.72	4.74	4.74
	(24)	(23)	(22)	(21)	(20)	(19)	(18)	(17)	(16)	(15)	(14)	(13)
	4.78	4.80	4.80	4.78	4.80	4.80	4.68	4.68	4.70	4.76	4.72	4.70

B

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
	4.86	4.84	4.84	4.80	4.82	4.86	4.74	4.76	4.72	4.76	4.78	4.78
	(24)	(23)	(22)	(21)	(20)	(19)	(18)	(17)	(16)	(15)	(14)	(13)
	4.78	4.80	4.80	4.76	4.80	4.82	4.68	4.70	4.70	4.76	4.82	4.80
Means	4.810			4.813			4.706			4.757		

II. $\rho \times e/m$

NPE I	NPE II	NPW I	NPW II
1.076	1.038	1.083	1.030

Mean NPE = 1.057 Mean NPW = 1.057
Mean I = 1.080 Mean II = 1.034
Final mean (I and II or NPW and NPE) = 1.057

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* This is the resistance in the induction circuit in ohms.

† A_0 I and A_0 II are the minimum amplitudes for the positions I and II of the half-cycle asymmetry switch.

In the practice of the method it is important that the natural frequency of the system be identical in (1) and (2), and thus that the heating effect of the magnetizing coil be the same in the two cases. For this reason the magnetizing coil in (2) is traversed by a current of the same magnitude as in (1), but from an independent source with a *frequency so remote from that of the vibrating system*, or any of its low odd harmonics, that it produces no appreciable amplitude.

If the waves of c and μ are *strictly rectangular*, whether the gap width is small or large, and if the contact resistance between brushes and commutator segments is independent of the motion, the ratio of C to μ_0 in (6-1, 2, 3) is equal to the ratio of the steady current in (2) to the value of the magnetic moment of the rotor for the steady value of the magnetizing current in (1), *while the commutator is at rest.*

As a matter of fact the waves are, of course, not strictly rectangular, and their shapes differ on account of the difference between the time constants, the difference between the sparks at the commutator, and hysteresis. With low frequencies the assumption of true rectangular waves is much nearer the truth than with high frequencies, so that lower frequencies will, other things being equal, give better results than higher.

In the method as finally practised, the current C was produced by a voltaic cell in series with a high resistance box, and the steady value of the current for (2) was determined as the ratio of the electromotive force to the total resistance of the circuit; while in (1) the mean magnitude of the commutated magnetizing current was maintained steady as read accurately from an ammeter on the battery side of the commutator. In separate experiments the ratio of the steady current with the commutator at rest to this mean commutated value was repeatedly determined.

Moreover, from the fact that the time constant in (1) is greater than that in (2), it is easy to show that even if the gap correction were zero the apparent value of ρ would be too large, the inequality being greater the greater the time constant in (1), and the greater the frequency. Errors arising from these causes, together with the necessity of measuring accurately several quantities not needed in the determination of ρ by the other methods, are the chief disadvantages of Method II.

While the method clearly has disadvantages as compared with Method I, it has one advantage in that no secondary circuit is used, so that there is no chance of a leak between the two circuits introducing an extraneous torque with its attendant possible systematic error. By paying proper attention to insulation this torque can always be made small; and if it is in phase with the applied electromotive force as assumed in the earlier papers, it will be in quadrature with the gyromagnetic torque and without effect on the results. In this work great attention has always been paid to the insulation between the two circuits, and the measured leakage through the secondary with a galvanometer in series has always been very minute in comparison with the current due to the changing magnetic moment of the rotor. Nevertheless some small discrepancies between results may possibly be accounted for by leakage on the assumption that the actual leakage current immediately after reversal of the commutator is much greater than the steady or nearly steady current measured quickly thereafter, and thus produces a phase shift of its first harmonic from quadrature with the gyromagnetic torque. Polarization effects in dielectric conduction are of course well known. There is thus an advantage in having available a method free from the possibility of such effects.

§ 7. Example of Method II. Table 2 contains the amplitudes obtained in a single set of observations on the 3.2 mm. cobalt-iron rotor, together with the resulting values of $\rho\, e/m$. A mean commutated current of 330.5 milliamperes traversed the fixed coil. The frequency was 4.54 cycles per second. The moment of the rotor (for the maximum value of the current commutated) was 1256 e.m.u. (ratio of maximum to mean current estimated as 361/350 from observations made later).* The moment of the permanent magnet m_0 was 0.746 e.m.u. Mirror holder No. 4 was used. The resistance of the torque coil circuit during the torque coil drive was 60,315 ohms, the e.m.f. of the cell 1.578 volt. Observations began at 3 a. m. and ended at 6:30 a. m.

For each of the azimuths *NPE* and *NPW* four groups of amplitude measurements were made, two of them, viz., *A* and *C*, with gyromagnetic drive, and two, viz., *B* and *D*, with torque coil drive. The order of the groups is *A*, *B*, *C*, *D*; and the order of observations within the groups is given by the numbers in parentheses. Each group contains 12 measurements of amplitude, half of them for each position (I or II) of the reversing switch. The interval between (3) and (4), and between (9) and (10) is 3 m. That between other successive observations within the groups is ½ m. The interval between successive groups is about 5 m. The values of $\rho\, e/m$ for the two azimuths and the two positions of the switch, together with the final means are given at the foot of the table, under II.

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* In later work this ratio was determined separately for each set, an improvement in the procedure being thus effected.

TABLE 2

Observations on 3.2 mm. Cobalt-Iron Rotor, May 28, 1936, and Results

I. 2 × Amplitudes in cm. ($2\,A_\infty$)

$2A_0$ I = 0.11					NPE						$2A_0$ II = 0.11
A						B					
G I			*G* II			*T* I			*T* II		
(1) 4.70	(2) 4.68	(3) 4.70	(4) 4.60	(5) 4.59	(6) 4.60	(1) 4.62	(2) 4.62	(3) 4.62	(4) 4.60	(5) 4.60	(6) 4.60
(12) 4.70	(11) 4.70	(10) 4.70	(9) 4.62	(8) 4.62	(7) 4.62	(12) 4.60	(11) 4.60	(10) 4.60	(9) 4.60	(8) 4.60	(7) 4.60
C						D					
(1) 4.70	(2) 4.70	(3) 4.70	(4) 4.60	(5) 4.60	(6) 4.50	(1) 4.60	(2) 4.61	(3) 4.61	(4) 4.57	(5) 4.58	(6) 4.58
(12) 4.70	(11) 4.69	(10) 4.70	(9) 4.60	(8) 4.60	(7) 4.60	(12) 4.54	(11) 4.54	(10) 4.55	(9) 4.57	(8) 4.56	(7) 4.57
Mean G_{I} 4.697			Mean G_{II} 4.603			Mean T_{I} 4.592			Mean T_{II} 4.587		
$2A_0$ I = 0.08			Mean $2A_0$ I = 0.095			Mean $2A_0$ II = 0.140			$2A_0$ II = 0.17		
NPW											
Mean G_{I} = 4.677			Mean G_{II} = 4.652			Mean T_{I} = 4.630			Mean T_{II} = 4.623		
Mean $2A_0$ I = 0.115									Mean $2A_0$ II = 0.040		

II. $\rho e/m$

NPE			NPW		
I = 1.061	II = 1.040	Mean = 1.050	I = 1.048	II = 1.044	Mean = 1.046
Mean of all = 1.048					

§ 8. Method III. This is the single straight line form of the graphical method of III § 46 and VI § 30A, with the strict time schedule, the repetition of observation of each kind at half-minute intervals, and the reversals for asymmetry (as well as reversals in azimuth) as practised in the use of the other methods. The amplitude is observed and plotted as a function of the conductance X of the induction circuit for each azimuth and each direction of the asymmetry switch; and for each arrangement $X_0 + \delta X_0$ is obtained from the intersection with the axis of X of the symmetrical straight line best representing the observations and drawn across the axis X. The schedule is so arranged that for each azimuth the mean times are identical for all the values of the conductance and both directions of the asymmetry switch. The mean value of $X_0 + \delta X_0$ is the value X_0 sought, from which ρ is calculated as in Method I.

In the new work only a few observations have been made by this method.

B. Apparatus: Construction and Constants

§ 9. Rotor and Suspension Construction. Many of the rotors used in this later work have been constructed on the anti-magnetostriction principle used in building the complex cobalt, nickel, and iron rotors described in IV and VI.

As in the case of the standard short rotors of the earlier work, designed to be used with the fixed magnetizing coil only, or with both fixed and moving coils, the magnetic material in most of them has been about 8 cm. shorter than in the case of the standard long rotors. Other rotors have been constructed like the earlier standard short rotors, some with and some without winding. Every rotor has the same total length.

In the most recent complex rotors the terminal construction differs from that described in V, the end of the rotor being turned down to a small diameter, and fitting, with small clearance, in a central cylindrical hole machined in the cap. Also, in some cases, the central tube between the magnetic rod and the brass sheath, which is thoroughly soldered to both, has been increased in length to about 1.5 cm. to assist in keeping the rod and sheath coaxial without strain and with minimum friction at the bearings.

In much of the work the rotors have been connected with the mirror-holder, and this with the lower suspension, by rectangular hooks and rings such as were always used in the earlier work.* In the case of the more recent rotors, and that of earlier rotors recently modified, the ends of the rod (or brass tube) have been provided with threaded brass caps by means of which they can be rigidly screwed to a brass terminal at the bottom of an upper suspension and either to the top of one of the mirror holders of newer design, described below, or to a finely constructed universal joint which is screwed to the bottom of the rotor and to the top of the mirror holder. Flanges at the junctions assist in making the alignment exact and rigid. At least one of the flanges in contact is always slightly recessed, so as to make contact only along a rim at the outer edge.

All of the latest experiments have been made with the fixed magnetizing coil. This fact has made it unnecessary to provide a separate upper suspension and torsion head for each rotor. Three new upper suspensions have been constructed of No. 34, No. 32 and No. 28 German silver wire. Each is about 7 cm. long and is provided with an axially symmetrical brass terminal at the bottom. This terminal ends in a flat surface with a threaded hole in the center. Into this, with flange (or flange rim) against flange, is screwed the brass cap at the top of the rotor. New lower suspensions are similar, except that they are provided with rectangular hooks for attachment to the stretching weight.

The practical advantages of making experiments with unwound rotors are that the difficulty of straightening such rotors is very much less than that of straightening wound rotors, and that with the former it is unnecessary to use individual suspensions. The winding is also difficult and expensive; and the insulation of the windings, in spite of the greatest care and skill on the part of the mechanician, has often broken down and had to be replaced.

In all the recently constructed rotors provided with their individual upper suspensions, and in all of the new suspension caps, both upper and lower, the German silver wire has been anchored in place as described in IV, p. 134, footnote, and as illustrated in IV, Figure 5. In all recently constructed upper suspensions the wire, carefully centered and soldered in the lower portion of the torsion rod, has been brought out above through an oblique hole in the side, wrapped around the rod in a spiral, and soldered in place. No suspension anchored in this way has so far pulled out.

§ 10. THE MAGNET-MIRROR HOLDERS. The holder known as No. 3 (III p. 312) continued in use into the fall of 1935, with no deliberate change except that the gilding of the mirrors, which had become defective, was replaced by films of aluminum-magnesium alloy. This holder, however, made of pieces screwed and soldered together, proved insufficiently rigid. It was therefore replaced by No. 4.

The chief part of No. 4 was made from a continuous phosphor-bronze rod, slightly thicker than the brass rod of No. 3, of nearly the same length, viz., about 33 cm., and with a bronze hook and a square bronze ring* screwed and soldered into the ends, much as in No. 3. On the same side with the open space in the hook, as a counterpoise, was a bronze projection soldered near it to the rod. Bronze pieces to hold the mirrors and magnets were soldered to the rod and milled until their faces were parallel to one another and each pair nearly symmetrical with the axis of the rod. Four small projections, equal in height, were left on each face of the upper pair, and the mirrors attached to them, at first with shellac. Six equidistant grooves were milled in each face of the lower pair to fit magnets of the same kind used before. Two pieces of optically flat glass 6 x 7 mm.^{2} in area and 1 mm. thick were obtained for the mirrors, and coated with aluminum.

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* To facilitate the connection of the mirror-holder to the rotor, when the amber bobbin was in use, the rings at the lower ends of some of the newer rotors used as above have had their openings extended in the vertical direction, instead of being made square, as formerly. This was made necessary by the design of the new torque-quadrature-coil system.

* The ring at the bottom of the holder, into which a hook at the top of the lower suspension was fitted, was later removed and the end threaded. A small brass cap was then threaded to screw on to this end, and was soldered axially to the upper end of the German silver wire of a lower suspension.

Three additional holders, Nos. 5, 6 and 7, shorter, lighter, and simpler, were constructed. The principal part of No. 5 was made of a cylindrical rod of bronze cut from the same stock used in No. 4. Parallel and symmetrical flat surfaces were formed on opposite sides of the rod by a milling machine to hold two optically flat mirrors 1 x 4 x 6 mm. in dimensions; and two sets of 6 grooves parallel to these surfaces were milled for 2 x 6 magnets, similar to those used in the cases of No. 3 and No. 4, and similarly arranged. A rectangular hook of bronze, provided with a counterpoise, was screwed and soldered on to the upper end, and a suspension cap similar to that described in connection with No. 4 was screwed and soldered on to the lower end. The complete length of the holder was about 11 cm. The mirrors, covered with aluminum-magnesium alloy, were cemented on with asphalt, the longer sides being horizontal.

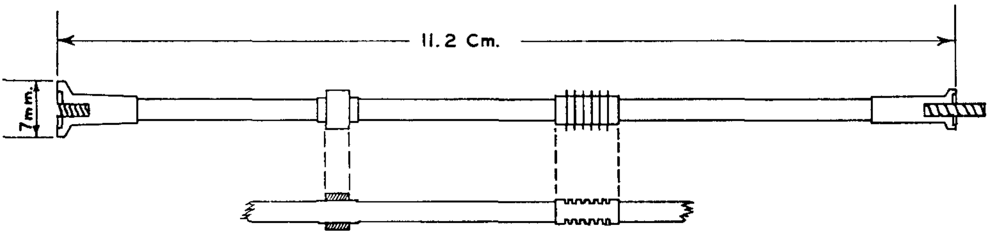

FIGURE 2. Magnet-mirror holder no. 7.

No. 6 was No. 5 modified as follows. The ends were cut off, and axially symmetrical brass caps were screwed and soldered on. The caps were centrally threaded and provided with flanges for accurate and rigid connection to the new type of rotor and lower suspension described above. The upper flange, like that at the bottom of the rotor, was about 7 mm. in diameter; the lower about 5 mm.

No. 6 turned out to be quite imperfect, the surfaces of the flanges not being quite parallel. As soon as possible it was therefore replaced by No. 7, which was practically perfect.

Holder No. 7 had nearly the same dimensions and appearance as No. 6. It is illustrated in Fig. 2 which is drawn nearly to scale. The mirrors and magnets were similar to those used in No. 6, and were put on in nearly the same way. The rest of the holder was turned from a single Tobin bronze rod, except for the screw at the lower end, which was made separately for mechanical reasons.

Nos. 5–7 were constructed in order to make the whole vibrating system shorter and more rigid, with the hope of reducing any error due to a possible difference between the effects of driving the rotor with the torque coil and with the magnetizing coil. The subject will be discussed further in § 33.

A diagram showing the relative lengths of the different holders and the locations of the magnets and mirrors is given in Fig. 3.

The magnets of No. 4 were at first put on with shellac, as formerly. Magnets put on it this way cannot be properly heat-treated to maintain their moments constant, a fact which has cost us a large amount of labor. Afterward they were removed and put on with the diamagnetic cement known as "insolute," as were also those of No. 5. The insolute, which is very brittle, was finally replaced by uncolored glyptal, which is both diamagnetic and exceedingly tough. This was used with Nos. 6 and 7 also. After being cemented in place with insolute or glyptal, the magnets were heated at the temperature of boiling water for a day and a night, after which the systems appeared more stable than those not subjected to heat treatment.

Holder No. 4 was later further modified, terminal flanges and screws similar to those of Nos. 5 and 6 being made to replace the hooks. In this state it was designated No. 8.

In all recent work the mirrors, as suggested by Mr. Julius Pearson, have been attached with pitch, which, in case it distorts the mirrors initially, yields in such a way that the distortion soon disappears. It has produced no appreciable

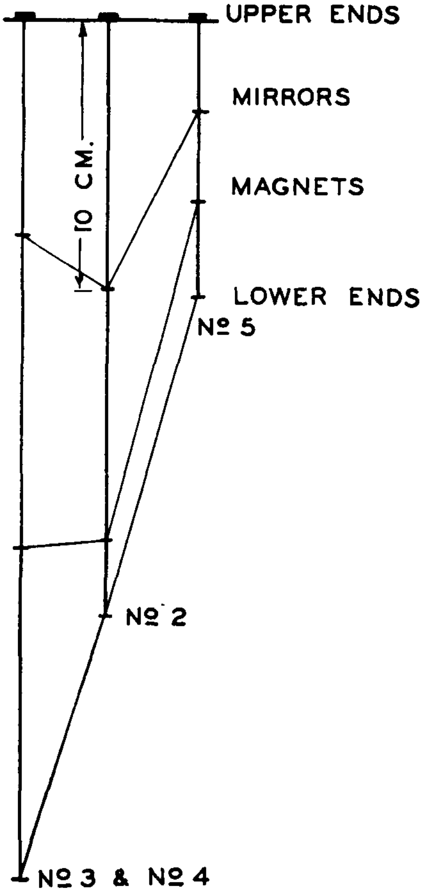

Figure 3. Relative dimensions of the different magnet-mirror holders. Numbers 6 and 7 have the same length as no. 5, no. 8 the same length as nos. 3 and 4.

distortion of our 1 mm. thick mirrors even initially.

For the optically flat glass used for all the mirrors referred to above, I am indebted to the kindness of Mr. Ellerman and Mr. Dalton of the Mt. Wilson Observatory; and for coating these mirrors, as well as other mirrors, with beautiful films of aluminum and aluminum-magnesium alloy, I am indebted to the kindness of my colleagues, Prof. John Strong and Prof. H. W. Edwards.

§ 11. Torque Coils and Quadrature Coils. In the interest of better insulation the twin-wound torque and quadrature coils *B*, and their facsimile compensators, were replaced by coils of nearly the same dimensions, but wound in separate channels in ebonite side by side. The outer pair of one combination constituted the torque coil *C*, the inner, the quadrature coil *C*. The coils were impregnated and covered with white ceresin wax to protect them and to improve the insulation. This was at first very high but soon greatly decreased. There are two varieties of white ceresin wax, one of which, the "natural" variety, appears greatly to surpass the other in surface insulation in moist atmospheres. On the suspicion that the inferior variety had been used, the coils were removed from the bobbins, which were cleaned, and then rewound to nearly the same dimensions. They were then impregnated with "natural" ceresin wax. This gave us torque coil *D*, with its quadrature coil, and the compensators. The constants of the new torque coils, and one of the quadrature coils, were determined electrically with precision by the methods used with *A* and *B*. The constants of torque and quadrature coils *C* were found to be 1129.8 and 2132.1 e.m.u. respectively. The constant of the torque coil *D* was found to be 1083.8 e.m.u.

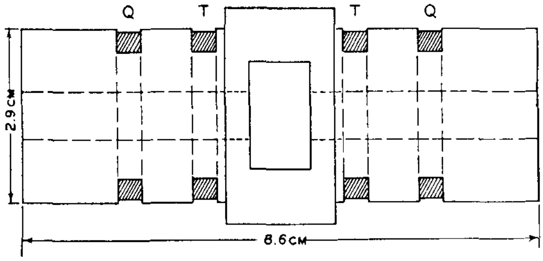

Figure 4. Torque coil (TT) and quadrature coil (QQ), system E. Horizontal section through axis.

In order to increase the insulation still further and at the same time to provide coils with constants still more nearly unalterable with time, and with smaller magnetic moments for use with the short magnet-mirror holders Nos. 5–8, another set of torque and quadrature coils of improved design, *E*, was constructed with coils of smaller diameter and a bobbin entirely of amber, in one piece. The coils were covered with natural ceresin wax. A duplicate was constructed to serve as mutual inductance compensator. The details of construction are given in Fig. 4. The inner two coils were used in series as torque coil, the outer two in series as quadrature coil.

The constant of the torque coil was 1009.6 e.m.u., that of the quadrature coil about 246.8 e.m.u. Both were measured with precision. Each (double) coil contained 2 x 300 turns with a mean diameter of about 2.4 cm., so that its magnetic moment per ampere was about 270 e.m.u. The mutual inductance *M* between the torque coil and the quadrature coil (as between the corresponding coils of the compensating set) was about 11 x 10^5 e.m.u. As in the earlier work the two sets of coils were connected in the circuit in such a way that their mutual inductances almost completely annulled one another.

§ 12. INDUCTION SOLENOIDS AND FIXED MAGNETIZING COILS. With the hope of improving the insulation between the two circuits the upper part of the 1¼ inch induction solenoid and its compensator were for a time replaced by exactly similar coils wound on ebonite instead of bakelite. As no apparent improvement resulted (perhaps in part on account of an accident to the tube on which the induction solenoid was wound), and as the bakelite was much superior in permanence of form to the ebonite, the old coils were soon replaced.

For all work done with the magnet-mirror holders Nos. 5–7 and for some other measurements, it was necessary to remove the extension at the lower end of the induction solenoid. The removal lowered the constant of the coil (for a standard short rotor) by only a small fraction of one per cent, viz., from 216.8 to 216.3 e.m.u.

Still later, in order to make the whole suspension system shorter, and at the same time to place the rotor more nearly at the center of the fixed magnetizing coil, this coil and the induction solenoid, together with the tubes on which they were wound, were shortened, the length of the windings on each being reduced to about 37.2 cm., while the two lower ends were kept at the same level as formerly. Suitable changes were made in the compensating coil arrangement. According to experiments made with the cold-rolled steel and electrolytic iron rotors, the constant of the induction solenoid for the short rotors was not appreciably altered by these changes.

To remove any possibility of doubt of the insulation between the two layers of the fixed magnetizing coil (including the leads attached to each end), after a breakdown at the terminals had ruined a number of observations, the terminals were at first thoroughly repaired (Sept. 1934). Then, for a still greater degree of certainty, the coil was rewound with cotton tape, and later with silk tape, between the two layers. In the last case one of the layers was wound in a left hand spiral, the other in a right hand spiral. The two were connected at the bottom to pins between which a thin wire was soldered.* When the wire was removed the insulation resistance could be readily measured. Corresponding changes were made in the mutual induction compensating solenoids. The insulation in both cases always remained perfect.

In order to reduce heating, the following steps were taken. Eight wires were removed from the upper end of the induction solenoid (not enough to alter its constant appreciably), and a ring of holes bored in their place. At the same time V-shaped grooves were filed all around the edge of the lower insulating ring of amber. This made possible a steady convection current of air between the magnetizing coil and the induction solenoid. Also, holes bored laterally into the lower portion of a new amber bushing which topped the magnetizing coil and held the torsion-head made possible ventilation of the space immediately surrounding the rotor and suspension. V grooves, similar to those in the amber ring at the bottom of the magnetizing coil, were cut in the two rings at the ends of its compensator.

In order to use stronger magnetizing fields and at the same time to avoid greater forcives on the permanent magnet, still another magnetizing coil was constructed. It was 36.2 cm. long and was closely wound in four layers (without insulating tape in between) on a bakelite tube with internal and external diameters 8 and 11 mm. Otherwise the coil was similar to the magnetizing coil just described. It was mounted centrally inside a new induction solenoid, identical so far as the winding is concerned with that carrying the earlier coil, and with proper provision for ventilation. A duplicate was wound to form part of the mutual induction compensator. The new coil when producing twice the magnetic intensity of the older had a moment considerably less, and its lower end was slightly farther from the permanent magnet.

§ 13. FREQUENCY CONTROL. In order that the natural frequency of the rotor system might remain as nearly constant as possible throughout a complete set of vibrations, we long ago adopted the practice of establishing in the magnetizing coil long before the beginning of the set an alternating current with approximately the same heating power as that of the experimental current, but with a quite different frequency. Improvements, made some time ago, consisted in substituting a thermoammeter for another type of instrument used in equalizing the currents, and in preheating for a longer period—ordinarily four hours at least. The tuning fork also is kept in operation throughout this period.

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* Initially the connection between the two layers was made by long closely twisted wires connecting to a switching device mounted at a distance on the frame of the vertical intensity coil. In spite of the twisting, however, these wires produced a decided torque on the permanent magnet, and were removed.

The adjustment of the fork has been made easier by means of the additions illustrated in Fig. 5. A brass lug *B* is secured to the end of each prong *A* by means of two steel screws, one of which, *C*, is shown in the figure. The lug is threaded to hold the heavy steel screw *D* provided with a large brass head *E*. The lug is slotted, and the screw *D*, when not being turned for frequency adjustment, is clamped by the steel screw *F*.

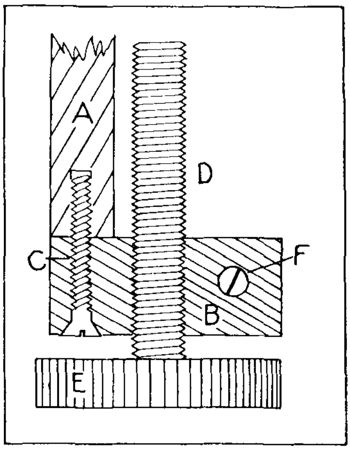

FIGURE 5. Tuning fork extension for frequency adjustment.

§ 14. THE MOMENTS OF THE ROTORS. The procedure used in determining the moments of the rotors was not discussed in III and V. In the practice of Methods II and III the magnetic moment of the rotor is needed only for estimating errors, calculating small corrections, and estimating vibration amplitudes to be expected, and need not be precisely determined. For Method II, however, exact measurements are necessary; and such measurements were almost always made even when this method was not to be used. The ballistic method of reversals was used. The rotor was hung in its standard position within the induction solenoid, or within both this solenoid and the fixed magnetizing coil, and the change of flux $\delta\varphi$ through the induction solenoid (constant $= \gamma_0$) produced by the reversal of the proper current in the magnetizing coil, either fixed or movable, was compared with the change of flux $\delta\Phi$ produced by the operation of a Hibbert magnetic standard. This latter was itself calibrated by means of a standardized ammeter and a mutual inductance standard made of the author's double solenoid* and an accurately constructed and placed secondary coil at the center. From the throws, the value of $\delta\Phi$, and the relation $\delta\varphi = 2\gamma_0 \times$ *the magnetic moment of the rotor*, this moment is determined. This moment is μ, that of the magnetic material alone, when the fixed magnetizing coil is used; or $\mu + \mu'$, where μ' is the moment of the coil wound on the rotor, when the magnetizing current is sent through this coil. The moment μ' is always calculated as the product of the total area of the winding × the current. When the fixed coil is used, care is, of course, taken to see that the mutual inductance compensation is made with the degree of precision necessary.

While the measurements of rotor moments were almost always exact, they were not in general made for the *maximum* value of the commutated current, except as needed for Method II. Often they were made for a number of different currents. The values given in the text (except when Method II is involved) are in general the moments for the *mean* value of the commutated current.

§ 15. TESTING FOR ANNULMENT OF THE EARTH'S VERTICAL INTENSITY. Inquiry has been made as to the method of testing for the annulment of the vertical component of the earth's magnetic intensity in the region occupied by the rotor.

In the earlier work, as explained in III, and in much of the later work, this was done with the horizontal intensity magnetometer and two earth inductors. One of these was mounted, at the times of primary calibration only, in the place ordinarily occupied by the induction solenoid and its supports at the center of the vertical intensity coil. The other is permanently mounted near the magnetometer and coil and serves only to compare the horizontal and vertical intensities both at the times of calibration and at the times of measuring the effect under investigation.

As it is extremely inconvenient to remove and reset the induction solenoid for repeating primary calibrations, two other methods have more recently been used. In the more satisfactory, arrangements are provided by which a comparatively small flip coil can be quickly mounted and properly operated in a position close to the center of the vertical intensity coil without disturbing the induction solenoid. Instead of using the magnetometer and comparing the horizontal and vertical intensities, it has been more convenient to cut the flux due to the vertical intensity only with the external inductor, and to use a Hibbert magnet and coil as an intermediate standard.

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* A double solenoid for the production of uniform magnetic fields. Phil. Mag. **40**: 519, 1920. See also Glazebrook, Dictionary of Applied Physics **2**: 454.

If Z_0 denotes the current necessary to annul the vertical intensity at the time of calibration, T_0, and Z that at the time of observation T; D_0 and D, the corresponding earth inductor throws; and S_0 and S, the corresponding Hibbert-Standard throws; we have for Z the relation

$$Z = \left(Z_0 \frac{S_0}{D_0}\right) \frac{D}{S}$$

It has never been necessary, as explained in III, to make measurements of Z_0 except at long intervals, as the proper value of Z on any occasion can be obtained from the standard determination Z_0 and the subsidiary observations made on the occasion. Throughout most of the work these subsidiary observations have been made for every group, or nearly every group, of vibration observations. But the response to small variations in Z is usually so slight as to make exact settings unnecessary, and in some of the work the observation for Z have been made only at considerable intervals, with the certainty that the slight variation of the current from its proper value for exact compensation would make no appreciable difference in the results.

§ 16. THE CONSTANT OF THE LARGE HELMHOLTZ COILS. This constant enters twice into the formula for ρ, once in determining m_0, the moment of the vibrator magnet, and once in determining Γ_0, the constant of the torque coil. An exact knowledge of this quantity is thus of great importance. As additional evidence of the correctness of its value as obtained from the absolute measurements it may be stated that this value has twice been checked by comparing the constant electrically, once in 1926 and once in 1934, with the constant of the 10 cm. subsidiary Helmholtz coil referred to in III § 34 and illustrated in Fig. 34-1 (*CC–DD*) of that paper. The constant of this coil, as calculated from its dimensions, is 39.32 e.m.u. with an error estimated as about 0.1 per cent. The earlier and later electrical comparisons with the large coil gave 39.35 and 39.33 e.m.u. respectively, thus indicating no appreciable error in the constant of the large coil.

§ 17. CORRECTIONS ASSOCIATED WITH m_0. A slight correction to the values of m_0, and thus to the values of ρ given in III and IV, viz. the fraction + 0.002, has been found necessary because the earlier magnetometer observations for lack of proportionality between deflection and intensity were made without the control magnet in position, while it was present during the regular observations for determining m_0. Also, a small correction, viz. the fraction − 0.003, has had to be made to a few of the results because in determining m_0 for them a certain bakelite support for the magnet-mirror holder was used. The width of this holder was determined shortly after it was made, and the result was used in the distance calculations. Later it was found that the support had shrunk slightly, a fact making the calculated values of m_0 and ρ a little too high.

There is, of course, always an error in m_0 due to the fact that when it is measured the axis of the magnet system cannot be set *exactly* horizontal. Also there is an error due to the fact that during the vibration experiments, the mean position of the axis is not *exactly* perpendicular to the axis of the torque coils. The first error makes the calculated value of m_0 (and therefore that of ρ) too small; the second makes the calculated value of ρ too large. The errors due to the inexactness of these settings were both, in general, so small as to be quite negligible; moreover, as just indicated, they tend to counteract each other.

A further fractional correction + 0.001 has been applied because of a new determination of the distance between the edges of the grooves in the Helmholtz coil holder used in measuring the distance r between magnet centers while m_0 is being measured.

§ 18. REPEATED DETERMINATIONS OF CONSTANTS. As indicated in III, V, and VI, and in part of what precedes in this paper, all of the constants involved in the determination of ρ from equation (4-2) have been determined repeatedly; and they have been determined so precisely that it is believed no residual errors in them can be responsible for errors of any consequence in ρ.

In this connection it should be said that in the recent work the separate determinations of the magnetic moment m_0 have been even more elaborate (ca. 25 per cent) than for III, and that in the course of the whole investigation over 180 determinations of this quantity have been made—in the mean about one for every three complete sets of observations for ρ recorded in the tables, of which there are more than 550.

Other constants which are important but which do not enter into the calculations are those of the coils whose currents X, Y, and Z compensate the N–S, E–W, and vertical components of the intensity of the earth's magnetic field. Alterations, or suspected alterations, with the time of the frames on which they are wound; and alterations or suspected alterations in the magnetic field of the laboratory due to time, to shifting of iron in connection with work going on in the building, and to the erection of a new building immediately adjacent, have made necessary repeated determinations of these constants. In the course of the whole investigation the X and Y coils have been calibrated 26 times, the Z coils 6 or 7 times.

C. FURTHER CONSIDERATION OF SOURCES OF ERROR IN THIS WORK

§ 19. THE POSSIBILITY OF ERROR DUE TO EXTRANEOUS TORQUES UPON THE MAGNET-MIRROR HOLDER DUE TO THE TORQUE AND QUADRATURE COILS. The magnet-mirror holder, which hangs in the alternating field of the torque and quadrature coils, is subject to an Elihu Thomson torque on accounty of asymmetry. This has no component of the fundamental frequency of the suspended system if the system is at rest. When the system is oscillating, however, it may be shown that there is a component with the fundamental frequency. This is doubtless exceedingly small, and if appreciable in this work would give values of ρ dependent upon the amplitude; whereas no such difference has been observed. A direct electrical effect seemed possible, though improbable. To test for any extraneous effect of the coils the following experiments were made.

The magnets were removed from holder No. 4 and the Cobalt-Iron rotor mounted and tuned by altering the compensation of the earth's field while the rotor magnetizing coil was traversed by the usual magnetizing current. This was then replaced by a current of the same magnitude at 50 ∼/sec, which produced no oscillation but maintained the temperature unchanged. The torque coil was then traversed by currents of 50 and 100 milliamperes at the fundamental frequency. Only three or four mm. double amplitude resulted whether the system was mounted symmetrically or turned through an angle of about 2°. The current normally traversing the torque coil in the principal experiments is of the order of 10^{-5} ampere—that is, of the order of 10^{-4} the currents used in the above experiment. Thus in the actual research no possible appreciable effect could be produced in this way. Similar experiments were made with a thin Hipernik rotor replacing the Cobalt-Iron rotor, and the effects were very much smaller with a current of 100 milliamperes, whether torque coil or quadrature coil (which had a much greater constant) was used. The observed effect is probably due largely if not entirely to the residual horizontal permanent moment of the rotor.

§ 20. TORQUES EXERTED BY THE FIXED MAGNETIZING COIL ON THE MAGNET-MIRROR HOLDER AND ITS PERMANENT MAGNET. When the later of the 2-layer fixed magnetizing coils is traversed by a current of 0.35 ampere (producing within the coil a magnetic intensity near to 20 gausses, designated by $H = S$ in this paper) it produces at the position of the permanent magnet on holder No. 3, No. 4 or No. 8 the intensity ca. 0.0095 gauss. At the position of the magnet in Nos. 5, 6, 7 it produces the intensity ca. 0.07 gauss. The intensities due to the other fixed coils traversed by the same current are still less.

These intensities are vertical for perfect symmetry, but otherwise have horizontal components, whose in-phase effects are eliminated, when appreciable, by the reversals already described.

The vertical intensity produces on the fixed magnet a torque about a horizontal axis, which, on account of asymmetry, may produce an axial vibration. The effect of such a torque is not eliminated by either of the reversals made in this work. If appreciable, it should be much greater for the short magnet-mirror holders than for the long; and any in-phase effect should show in a difference between results obtained with the two.

To investigate the magnitude of the torques involved for imperfect symmetry the following experiments were made. The brass rotor (without winding) was suspended with each of the holders Nos. 4 and 5 in succession and driven at resonance by the torque or quadrature coils while the standard current 350 milliamperes traversed the 2-layer magnetizing coil. The torque and the amplitude were measured when the holder was displaced from the position of symmetry as much as practicable (about 3 mm.) in the direction normal to the axis of the magnets. Then the current was annulled in the torque or quadrature coil, while it continued to traverse the magnetizing coil, and the amplitude was again measured. From the two experiments the torque due to asymmetry is readily determined. In the case of No. 4 no appreciable amplitude resulted in the second experiment, showing that the torque was less than 10^{-5} dyne cm. In the case of No. 5 the corresponding torque was about 4 or 5×10^{-4} dyne cm. When the regular gyromagnetic measurements are in progress, the magnet is never displaced from the axis of the magnetizing coil by more than a small fraction of a mm., so that the torques involved are very much less than those just given.

If the vertical intensities given above were horizontal, and normal to the axes of the magnets, they would produce the approximate axial torques 66×10^{-4} and 500×10^{-4} dyne cm., the exact values of course depending on m_0.

§ 21. EXTRANEOUS TORQUES ON ROTOR'S MAGNETISM DUE TO QUADRATURE AND TORQUE COILS AND TO FIXED MAGNETIZING COIL. A. QUADRATURE AND TORQUE COILS. In III § 12 it is shown that there is no appreciable torque on the rotor due to the action of the torque coil on its permanent magnetization, even when the center of the torque coil was only 20 cm. below the lower end of the rotor, a distance which in most of the work (with magnet-mirror holders Nos. 3 and 4) has been greatly exceeded. The torque due to the quadrature coil is usually much less than that due to the torque coil.

These torques are negligible even with the torque and quadrature coils E and the magnet-mirror holders Nos. 5–7, in the use of which the distance from the lower end of the rotor to the axis of the coils is only about 16 cm.

Thus the intensity at the lower end of the rotor due to the torque coil bears to the intensity it produces at the center of the coil, where the vibrating magnet with moment 0.7 e.m.u. is placed, the approximate ratio $2700/16^3$ to 1013, which is less than 7×10^{-4}. This coil, with magnet-mirror holder No. 5, was used with the 2.4 mm. nickel rotor, whose moment alternated between plus and minus 327 e.m.u. in the principal experiments. If we make the *extreme* assumption that the rotor is permanently magnetized to this value, and that on account of asymmetry the axis of magnetization makes an angle as great as 1/200 radian (1 mm. in 20 cm. of length) with the vertical, and if we further assume that the asymmetry is in a plane normal to the axis of the coil, the ratio of the direct torque produced on the rotor by the coil to the torque it produces on the permanent magnet with moment 0.7 e.m.u. (equal to the gyromagnetic torque when the vibration is annulled) will be

$$\frac{7 \times 10^{-4} \times 327}{0.7 \times 1013 \times 200} = 1.6 \times 10^{-6}$$

The effect of the coil on any cross-magnetization due to the full horizontal intensity of the earth's field is still less.

B. FIXED MAGNETIZING COIL. (1) In addition to other effects produced by this coil, attention is called in VI to a torque which seems to be quite appreciable in some of the recent work described here, viz., a torque on the rotor about a horizontal axis due to the action of the alternating vertical intensity on the permanent part of the horizontal moment, ξ. This produces a relative displacement of the rotor and suspension and thus, on account of the absence of complete symmetry about the vertical axis, gives rise to a torque about this axis which may have any phase relation with the gyromagnetic torque g. It has the frequency of the current and does not change sign or magnitude with the reversal of the system in azimuth. Its mean tends to disappear when the rotor is repeatedly mounted at random, but its existence may be responsible for some of the observed differences for which no other explanation has been found.

(2) There is also another torque, not mentioned in VI, which may possibly affect appreciably the results of all others who have worked with the fixed coil arrangement, but which is eliminated in the author's work by the asymmetry reversal I–II. It is a couple about a horizontal axis due to the action of the vertical intensity of the alternating field on the horizontal alternating moment ν. By reason of asymmetry and on account of the suspension displacement there results a couple about the vertical which has the frequency of the current and may have any phase relation with g. It tends to vanish with many settings of the rotor at random, but can be eliminated from results obtained with one setting only by the reversal I–II.

§ 22. NEGLIGIBLE EFFECT OF MUTUAL INDUCTION BETWEEN QUADRATURE AND TORQUE COILS. As is stated in V, one effect of any mutual induction between the quadrature and torque coil systems is to produce in the induction, or secondary, circuit an electromotive force (and current), and therefore a torque, nearly in phase with (or in opposition to) the gyromagnetic torque; and such an effect would have been negligible in the work described there even if the mutual inductances of the two parts of the systems had been made to add up instead of to compensate one another. Here it will be shown, in a somewhat different way, that the effect (even with the mutual inductances acting together in the circuit) is negligible even in the most unfavorable cases in the new work.

Thus, if the quadrature coils were traversed by a current with amplitude I, and the two sets of coils were connected so that their mutual inductances would add instead of subtract, the ratio of the e.m.f. induced by the quadrature coils in the induction circuit to that induced by the changing moment of the rotor would be $2M \omega I/\gamma_0 \omega \mu = 2MI/\gamma_0 \mu$, where M, as in V, designates the mutual inductance of one pair of the coils.

The most unfavorable case in the new work is that of the pure cobalt rotor when used with the torque-and-quadrature coils C. In this case $2M = 34 \times 10^6$, I (maximum value) $= 3 \times 10^{-7}$, $\gamma_0 = 216$, and $\mu = 73$, all in e.m.u. This gives for the ratio the number 0.00065.

Much of the new work has been done with the torque-and-quadrature coils E, for which $2M$ has the much smaller value 22×10^5 e.m.u. A very unfavorable case is that of the 2.4 nickel rotor ($\mu = 327$) for which the maximum value of the quadrature current was 9×10^{-7} e.m.u. Thus the maximum value of the ratio for this rotor is about 3×10^{-5}. When these coils were connected for mutual inductance compensation, as in the measurements of the gyromagnetic ratio, the ratio of the torques was not greater than a minute fraction of this quantity, itself entirely negligible.

§ 29. TORQUE ON THE ROTOR POSSIBLY DUE TO THE PRESENCE OF ELECTRIC CHARGES. On one occasion, while working with the long 2 mm. wound permalloy rotor, we observed an amplitude of the order of 1 cm. which may have been due to a torque of this kind. It appeared only when the moving coil was in use, and then only when but one end of the coil was connected to the circuit. When the two ends were interchanged the phase of the torque reversed. It was always in quadrature with the gyromagnetic torque, and it disappeared when the circuit was closed even through a small condenser permitting only a current of one or two milliamperes to flow. The torque finally disappeared and we did not succeed in observing it again. For some time after this, and in order to prevent the possible accumulation of charges in the neighborhood of the rotor, we adopted the practice of inserting in a suitable receptacle projecting downward from the torsion head a small quantity of a salt of uranium. Later the practice was discontinued. To fix the relative potentials we have often made the connection between the primary and secondary circuits indicated by the dotted line in Fig. 1. But we have never observed any effect on the vibrations of making or breaking this connection.

§ 30. POSSIBILITY OF ERROR DUE TO THE INDUCTIVE ACTION OF THE VIBRATING MAGNET ON THE SECONDARY CIRCUIT. It is desirable to show that this error, which was not mentioned in III, is negligible in this work.

Let Γ_0 denote, as before, the constant of the torque coil, m_0 the moment of the magnet, and θ the angle between the axis of the magnet and the planes of the turns of the coil. Then, since θ is always very small, the flux φ sent through the torque coil by the magnet is

$$\varphi = \Gamma_0 \, m_0 \theta$$

The flux Φ sent through the induction solenoid (constant γ_0) in the same circuit by the rotor, with moment μ, is

$$\Phi = \mu \gamma_0$$

The ratio R of the electromotive force induced by the change of φ to that induced by the change of Φ is

$$R = \frac{\Gamma_0 m_0 \dot{\theta}}{\gamma_0 \dot{\mu}} = \frac{\Gamma_0 \, m_0 \, \bar{\theta}}{\gamma_0 \bar{\mu}}$$

$\bar{\theta}$ and $\bar{\mu}$ being the amplitudes of the angular motion and the moment of the rotor. The first electromotive force is clearly opposite to the second, and in phase with the gyromagnetic torque. It makes the apparent value of ρ too large by the fraction R, which, in this work, is always far less than the experimental error, as may be seen by making the proper substitutions in the formula.

§ 31. ESTIMATE OF ERROR DUE TO THE BRASS TUBE. That no appreciable error is introduced by the presence of the brass tube in which a rotor is sometimes encased may be shown as follows.

Let D denote the mean diameter of the tube, h its thickness, l its length, all in cm., and let σ denote its resistivity in ohm-cm. Then its resistance in ohms for a cylindrical current sheet about its axis is

$$R = \sigma \pi D/lh$$

Let $\mu = \mu_0 \sin \omega t$

denote the moment of the rotor in e.m.u., and φ

the magnetic flux through the tube in e.m.u. Then, approximately,

$$\varphi = 4\pi\mu/l = \frac{4\pi\mu_0}{l}\sin\omega t$$

The electromotive force in volts induced in the tube is

$$E = \dot{\varphi}/10^8 = \frac{4\pi\cdot\mu_0\omega\cos\omega t}{l10^8}$$

Thus the current in amperes is approximately

$$I = E/R = \frac{4h\omega\mu_0\cos\omega t}{\sigma D10^8}$$

and the magnetic moment of the current sheet, in e.m.u., is

$$m = I\frac{\pi D^2}{4\times 10} = \frac{\pi D h\omega\mu_0}{\sigma\times 10^9}\cos\omega t$$

$$= \frac{2\pi^2\nu D h\mu_0}{\sigma\times 10^9}\cos\omega t = m_0\cos\omega t$$

where m_0 is the amplitude of the moment of the current sheet and ν is the frequency in cycles per second.

The ratio of m_0 to μ_0 is

$$\frac{m_0}{\mu_0} = \frac{2\pi^2\nu D h}{\sigma\times 10^9}$$

If we assume a brass tube with $D = 0.34$, $h = 0.056$, and $\sigma =$ ca. 0.4×10^{-6}, together with a frequency $\nu = 10$, we obtain the result

$$m_0/\mu_0 = 0.0094$$

The effect of m, which is in quadrature with μ, is thus to produce in the induction circuit only a small electromotive force in comparison with that produced by μ. And this is in quadrature with the gyromagnetic torque, and thus ineffective.

§ 32. In-phase Torques due to the Normal Action of the Quadrature Coil on the Permanent Magnet. In V, § 6, three possible in-phase effects of the quadrature coil are considered, and it is shown that two of them are always negligible. The only one which can ever be appreciable is that arising from the fact that the wave forms are not strictly flat-topped and rectangular. Neither the time-constant of the magnetizing circuit nor that of the torque coil circuit is zero, and the two differ from one another; so that there is bound to be a shift of phase from pure quadrature. Let the amplitude of the gyromagnetic torque be denoted by G, that of the full torque due to the quadrature coil by Q, and that of the in-phase (or in opposition) torque due to the quadrature coil by I. Q/G is usually, but not always, small; and its mean (algebraic) value $\overline{Q}/G$ for all the parts of a set of observations is often much smaller. Moreover, I is in general a small part of Q, so that I/Q is often negligible. When Q/G is very large, however, and sometimes when it is not large, and especially at higher frequencies, the time constants and their difference may be so large in relation to the half-period of the vibration that I/G is quite appreciable, and the apparent values of ρ depend on $\overline{Q}/G$ in an unmistakable way. When $\overline{Q}$ is large it is sometimes variable from set to set, and a graph can be drawn between the apparent value of ρ and $\overline{Q}$, from which the true value of ρ can be obtained, as the intercept on the axis $\overline{Q} = 0$. Illustrations of this procedure will be found below.

In the greater part of this work the quadrature coil has not been used at all. Such a coil was first used by de Haas, in his work at Leyden, and with very low frequencies, for which it is much more suitable than for others.

§ 33. The Possibility of Error due to a Difference between the Effects of Gyromagnetic Drive and Torque Coil Drive. This subject has already been alluded to in § 10, where reasons are given for making alterations in the type of construction of the vibrating system. In the methods used in this work the rotor is driven in part by the gyromagnetic torque, which acts throughout the volume of the rotor, and in part by the torque produced by the torque coil on the group of permanent magnets, which have an entirely different location in the system. In the theory it is assumed that the two torques, for equal magnitudes, have equal effects. If they do not, different values of ρ should be obtained for holders with such different constructions as those of Nos. 2–8; and with any one holder different resonance frequencies should be obtained with separate gyromagnetic drive and torque coil drive.

Repeated experiments have shown, however, that the resonance frequency is identical whether the tuning is done by means of the gyromagnetic torque, by the torque coil, or by altering the degree of compensation of the earth's magnetic field while the magnetizing coil is in action. Our applied frequencies are remarkably constant, and the rotors are usually tuned to about one part in

15,000* of their natural frequencies. Also, no certain differences have been found in the values of ρ for the different constructions, or for the different methods of tuning. For many of the observations the tuning has been done with the gyromagnetic torque; and for many, with the torque coil drive or with the imperfect compensation referred to above. If there were any difference, gyromagnetic tuning or imperfect compensation tuning should favor the amplitude A_∞, torque coil tuning the amplitude A_2. The calculated value of ρ should then be too great for the first and too small for the second, as an inspection of the formula will show.

§ 34. STRETCHING WEIGHTS AND PARASITIC FREQUENCIES. In addition to its natural frequency for axial vibrations, each vibrating system has natural frequencies about horizontal axes, these being more numerous the greater the number of joints in the system. To prevent interference between these frequencies and the axial frequency it is necessary to choose a suitable stretching weight, as indicated in III, since the spurious frequencies are functions of this weight. Altogether we have used six weights, ranging in mass from 183 grams to 1,032 grams, some of them being hollow to make their moments of inertia large. For a long time we have regularly tested the suitability of a weight for given rotor, mirror holder, and suspensions by measuring the time for the amplitude of free axial vibration to decay to one half. This half-time may be only a few seconds for one weight, while it may be increased to 20, 30, or even 60 seconds in some cases by substituting a different weight. We have sometimes measured these spurious frequencies by impressing a horizontal magnetic intensity on the complete rotor, magnetized with a direct current, and studying the response as a function of the applied frequency. For a given rotor these frequencies are, as would be expected, approximately proportional to the square root of the weight. They are of course highly damped, and they are lower than they were at first thought to be. In some other cases we have simply looked for the small peaks in a long range resonance curve taken by means of the magnetizing current. Usually we have simply depended on making the half time large.

D. THE OBSERVATIONS AND RESULTS

§ 35. THE TABLES. The chief results of this work are given in a number of tables which will be found below in their appropriate places. H designates the magnetic intensity; the intensity $H = S$, near 20 gausses, being the standard intensity. MMH designates magnet-mirror holder; T.C. torque coil; A_∞ the (rough) mean amplitudes (in cm.) produced by the gyromagnetic torque and the effects in phase with and in opposition with it; A_0 the minimum (quadrature) amplitude; ν the frequency of the suspended system in cycles per second; μ the magnetic moment of the magnetic material of the rotor in e.m.u; μ' the moment of the coil (if present) wound on the rotor, also in e.m.u.

ρ designates the gyromagnetic ratio, or ratio of the angular momentum of the magnetic element to its magnetic moment; e/m, the ratio of the charge to the mass of an electron, the new value 1.757×10^7 e.m.u. being adopted. The gyromagnetic ratio of a (Lorentz) spinning electron being m/e, the column $\rho e/m$ gives the value of the gyromagnetic ratio of the element in terms of the ratio for the spinning electron on the assumption that only one kind of magnetic element is present.

E and W refer to the two azimuths of the permanent magnet of the suspended system, north pole east and north pole west; I and II to the two positions of the asymmetry reversing switch. Under the heading E–W, the figure I means the quantity obtained by subtracting the value of $\rho e/m$ for azimuth W from the value of $\rho e/m$ for azimuth E, both for the position I of the asymmetry switch. Similarly, the figure II means the quantity obtained by subtracting the value of $\rho e/m$ for azimuth W from its value for azimuth E, both for the position II of the switch. $\overline{\text{E–W}}$ is the mean of I and II, and $|\overline{\text{E–W}}|$ the mean magnitude.

Under the heading I–II, the letter E means the quantity obtained by subtracting the value of $\rho e/m$ for position II of the switch from its value for position I, both for the azimuth E. Similarly, the letter W means the quantity obtained by subtracting the value of $\rho e/m$ for position II from its value for position I, both for the azimuth W. $\overline{\text{I–II}}$ is the mean of E and W; and $|\overline{\text{I–II}}|$ the mean magnitude.

$\overline{\text{E–W}}$, $|\overline{\text{E–W}}|$, $\overline{\text{I–II}}$ and $|\overline{\text{I–II}}|$ have the same meanings in all tables, whether under the headings indicated above or not.

Half Sets of Observations. In the case of some of the very recent observations the calculations, instead of being made for whole sets as in Table 1, were made for half sets, as follows. The observations of (1) A (coupled with values of A_0 taken on both sides of it) were combined with those of (2) B (together with values of A_0 taken on both sides of it) and one value of $\rho e/m$ thus obtained. A second value of $\rho e/m$ was obtained by combining in the same way the observations of (1) B (together with values of A_0 obtained on both sides of it) and those of (2) A (together with values of A_0 on both sides of it). All calculations for each half set were thus referred to the same mean time. This process was adopted both because the precision of much of the later work seemed to warrant a reduction of the number of observations in a set and also because it gave an excellent check on the assumption made in the elimination of errors that the changes occurring were proportional to the time. In the tables the half sets can be distinguished from the others by the fact that two half sets taken together bear the same date.

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* Or even to 1 part in 30,000.

In addition to the great number of new observations on gyromagnetic ratios the results of which are included in the tables of this paper, a few others showing discrepancies not certainly explained completely are mentioned in the text.

§ 36. REJECTED OBSERVATIONS. The results of a number of observations have been excluded because they have little or no value on account of the unfavorable or uncertain circumstances under which the observations were obtained. Thus some have been rejected because quadrature amplitudes for at least one of the two azimuths (NPE and NPW) were too great to make reliable calculations possible; others, because of irregularities arising from fluctuation in the earth's magnetic intensity, from defects and maladjustments in the mechanical and electrical equipment, or from other sources. Some have been rejected because the in-phase (or in-opposition) torques of the quadrature coil were too large or too nearly constant (or the quadrature data otherwise inadequate) to make possible the extrapolation or interpolation necessary to eliminate their effects; others, because of short-circuits or bad contacts which developed in the electrical circuits and were not discovered until after the observations were over; or for other equally valid reasons.

The results of some of these observations, together with those of many rough and brief determinations made in the preliminary adjustments and tests of the rotors, might have been valuable in the early days of work on gyromagnetic phenomena, but they are now quite useless beside the great body of more reliable results.

§ 37. PERMALLOY. A summary of the results obtained on this material prior to August 8, 1929, when an important improvement was made in the elimination of errors, is given in Table 3 together with a summary of the results obtained on iron in the same period. All the results are reduced to the new value of e/m (1.757 e.m.u. instead of 1.77 e.m.u.) and for slight magnetometer corrections referred to above.

Table 4 contains important details of the results on permalloy between August 8, 1929 and January 12, 1930, of which only a still briefer summary was published in III; and Table 5 gives further details for the observations between May 23 and August 12, 1930, which were made, like all the later observations, on a much more rigorous time schedule.

While III was in the press the results of a few sets of observations on a 3.2 mm. permalloy rotor were added, more details for which will be found in Table 7 below.

These results are all remarkably consistent and seemed to leave little room for doubt as to the true value of $\rho e/m$ for permalloy. Nevertheless, after V, on cobalt and nickel, was completed it appeared desirable to seek a more precise answer to the question discussed in the next paragraph; and permalloy, on account of its comparative freedom from magnetostriction, was considered the best material to proceed with.

§ 38. EXPERIMENTS TO DETERMINE WHERE THE GYROMAGNETIC TORQUE IS APPLIED. As often pointed out before (first by O. W. Richardson), the torque measured in all experiments on the Einstein and de Haas effect is the combined torque on the rotor and the magnetizing coil. Theory indicates that the torque on the coil is zero,* and most experimenters in this field have measured the torque on the rotor only. In my own earlier researches, for greater certainty (and because certain undoubted sources of error can be avoided only by this procedure) the coil was usually wound on the rotor (as in the work of de Haas), so that the total torque was certainly measured. In others it was fixed to the earth. But, as pointed out in III, no certain difference was found between results obtained in the two ways, either with permalloy or with iron. The results with the coil fixed to the earth, however, were all obtained before some of the precautions taken in the later part of the work had been adopted. It therefore seemed desirable to make

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* For a rigorous demonstration see F. Coeterier, Helv. Phys. Acta **8**: 522, 1935.

TABLE 3

Gyromagnetic Ratios for Iron and Permalloy Obtained Prior to Aug. 8, 1929

Group	Method	Iron		Permalloy	
		No. Sets	$\rho e/m$	No. Sets	$\rho e/m$
I	Graphical-Null	18	1.049±0.010	30	1.059±0.013
II	Independent torque-coil and gyromagnetic drives			1	1.052
III	Large and small amplitudes	41	1.035±0.007	29	1.038±0.006
IV	Large amplitudes	3	1.037±0.011	12	1.043±0.008

TABLE 4

Results on 2.4 mm. Permalloy Obtained with Large Amplitudes and Approximate Elimination of Effects of Half-Cycle Asymmetry in Each Set. Moving Coil, $\nu = 10$, T.C.A. MMH No. 3. $H = S$ and ¼ S

Date	$\overline{\lvert\text{E–W}\rvert}$	$\overline{\text{E–W}}$	$\overline{\lvert\text{I–II}\rvert}$	$\overline{\text{I–II}}$	H	No. Sets	$\rho e/m$
Aug. 8, 1929–Jan. 12, 1930	0.034	−0.007	0.207	+0.033	S and ¼ S	26	1.048±0.011

TABLE 5

Results on 2.4 mm. Permalloy Obtained with Large Amplitudes and Complete Elimination of Effects of Half-Cycle Asymmetry in Each Set.* H = S; T.C.A.; MMH. No. 3. $\nu = 10$. Moving coil

Date 1930	E–W			I–II			$\rho e/m$	ΔZ†
	I	II	Mean	E	W	Mean		
May 23	+0.024	−0.010	+0.007	+0.138	+0.104	+0.121	1.048	0
May 28	−0.040	+0.039	0.000	+0.050	+0.129	+0.090	1.039	0
May 29	−0.037	+0.042	+0.002	+0.120	+0.199	+0.160	1.043	0
May 30	+0.045	−0.031	+0.007	+0.169	+0.093	+0.131	1.042	0
June 4	+0.024	+0.022	+0.023	+0.099	+0.097	+0.098	1.041	0
June 7	+0.026	+0.052	+0.039	+0.184	+0.210	+0.197	1.037	0
June 9	−0.031	+0.047	−0.008	+0.046	+0.024	+0.035	1.047	0
June 25	+0.027	+0.039	+0.033	+0.076	+0.084	+0.080	1.043	0
July 12	−0.024	+0.007	−0.008	−0.089	−0.058	−0.074	1.041	0
July 14	−0.024	+0.016	−0.004	+0.045	+0.085	+0.065	1.050	+6.0
July 17	+0.051	−0.031	+0.010	−0.204	−0.286	−0.245	1.047	0
July 22	+0.040	+0.001	+0.020	−0.235	−0.274	−0.254	1.050	0
July 25	+0.041	−0.032	+0.004	+0.227	+0.144	+0.186	1.043	0
Aug. 5	+0.007	+0.004	+0.002	−0.099	−0.102	−0.100	1.049	0
Aug. 9	−0.011	+0.005	−0.003	−0.191	−0.175	−0.183	1.043	0
Aug. 10	−0.056	+0.022	−0.017	−0.192	−0.114	−0.153	1.049	0
Aug. 12	+0.010	−0.044	−0.017	−0.114	−0.169	−0.142	1.042	0

$\overline{\lvert\text{E–W}\rvert} = 0.028$; $\overline{\text{E–W}} = +0.006$ $\overline{\lvert\text{I–II}\rvert} = 0.133$; $\overline{\text{I–II}} = -0.002$ Mean $\rho e/m = 1.044 \pm 0.003$

* One set, judged to be defective on account of a short-circuit, was rejected.

† ΔZ is the difference between the current in the coil compensating the vertical intensity of the earth's field and its value (ca. 94) for complete compensation.

a series of more precise observations in which the rotor was driven by the fixed and the moving coil in alternate sets.

Such observations, moreover, are very important for the additional reason that they furnish the only means of investigating the magnitude of the error which is discussed in § 21, B(1) and for the elimination of which from any set on a rotor not completely symmetrical no experimental procedure has been found.

For use in measurements with the fixed coil (as explained in III) the stationary magnetizing solenoid *A* (Fig. 1) was kept fixed in its normal position within the induction solenoid *B*, and connected in series with a similar solenoid *A'* within a coaxial coil *B'* similar to the induction solenoid, but longer, and having a few extra turns in series wound over the outside. By properly connecting the coils together and adjusting the axial position of *A'* with respect to *B'*, the effect of mutual induction was made to vanish when the rotor was absent and a current of 350 milliamperes (corresponding to an axial intensity $H = S$ near 20 gausses) traversed *A* and *A'*. The setting was made to a fraction of a millimeter; while a displacement of 2 cm. produced an effect equal to only about 0.1 per cent of that of the rotor. The setting for one position of the switch which was reversed when the azimuth of the suspended system was changed between NPE and NPW differed by only 5 mm. from that obtained several years earlier when the coils were new, and before the torque-coil-quadrature coil mutual inductance compensator had been introduced. After the first five sets with the fixed coil, however, it was found that the mutual inductance between the torque coil compensator (placed in the secondary circuit when the quadrature coil was introduced) and the outer fixed solenoid in the primary circuit did not quite vanish; and the total mutual inductance was thereafter adjusted to zero for each azimuth separately.* The difference between galvanometer throws for the two positions of the switch was about 1 part in 1,100 of that due to the rotor alone.

It has been found repeatedly that the setting for compensation is independent of the time during which the current has been flowing, as would be expected on account of the similarity of the two sets of coils, although the temperature distribution is not identical in the two.

Between November 8, 1933 and January 16, 1934, 21 sets of observations were made on the short 2.4 mm. permalloy rotor, with two layers of wire, the current in alternate sets traversing the coil attached to and moving with the rotor and the coil fixed to the earth. The results are given in Group I of Table 6. An entirely unexpected difference of about 1 per cent between the two groups immediately became apparent, the persistence of which made it necessary to extend the number of sets far beyond the limits planned. The difference cannot be explained by failure of the mutual inductance compensation, as it was found unaltered to less than 0.1 per cent in December, 1933, when this series was nearly completed. The only apparent source of error is that of § 21, B (1), which may be appreciable in the fixed-coil results.

These observations were not made to determine the absolute value of ρ, but to see whether an unexpected appreciable difference would be found between the values obtained with the two methods of measurement—magnetizing coil fixed to the earth and magnetizing coil rigidly wound on the rotor and moving with it. Hence it was unnecessary to know m_0 with precision; and all the calculations are based on the mean of two closely concordant values of m_0 obtained shortly before and after Group II. The last previous determination was made on March 8, 1933, eight months before Group I began. Linear interpolation between the value then observed and the value for Group II just referred to would give for Group I a mean value of m_0 one-half per cent higher, and this would raise the values of ρ for this group by that much. The probability is, however, that the proper value of m_0 for this group is nearer that adopted, viz., that for Group II, since the results show no certain variation with the time.

Not long after the completion of Group I the suspension pulled out of the rotor, which was further injured in certain tests. It was then rewound and otherwise thoroughly repaired, and remounted. Also, torque coil *B* was replaced by torque coil *C*, and great pains were taken in an attempt to improve the insulation, defects in which, it was thought, might possibly explain the discrepancy above noted. The mutual inductances were balanced, and a number of observations were obtained. They gave about the same fractional difference between the values of ρ for the two arrangements which had been obtained before. Absolute values were not needed, as explained above, and could not be calculated, as the constant of the torque coil was not determined till a good deal later—near the end of Group II. When the constant was determined, however, it appeared that the absolute values were all much higher than those of Group I. What is undoubtedly the true explanation of the difficulty was found only after the completion of Group II, in which it did not occur, and the first series on pure cobalt. It then became manifest that a partial failure of the insulation of the primary coil had occurred just at the terminals of the leads. When the leads were moved from

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* Later the outer coils were so placed and oriented that their mutual inductance completely vanished.

TABLE 6

2.4 MM. PERMALLOY. 1933–1935. MMH. NO. 3; ν = 9.6* AND 10†

Group	Date	Mag. Coil	H	T.C.	No. of Sets	$2 \times A_{\infty}$	$\lvert\overline{E-W}\rvert$	$\overline{E-W}$	$\lvert\overline{I-II}\rvert$	$\overline{I-II}$	$\rho e/m$
I	Nov. 15, 1933, to Jan. 15, 1934	Fixed	S	B	10	cm. 3.1–5.2	0.067	−0.003 ±0.002	0.071	+0.016 ±0.017	1.037 ±0.007
	Nov. 8, 1933, to Jan. 12, 1934	Moving	S	B	11		0.017	−0.007 ±0.004	0.058	+0.050 ±0.025	1.047 ±0.004
II	June 20–22, 1934	Fixed	S	C	2	3.1–4.3	0.129	+0.015 ±0.009	0.128	+0.028 ±0.000	1.031 ±0.003
	June 19–21, 1934	Moving	S	C	2		0.005	−0.003 ±0.002	0.024	−0.024 ±0.006	1.043 ±0.001
	June 26–28, 1934	Fixed	½S	C	2	2.3–3.5	0.264	−0.008 ±0.004	0.264	+0.075 ±0.039	1.035 ±0.007
	June 25–27, 1934	Moving	½S	C	2		0.005	−0.003 ±0.002	0.024	−0.024 ±0.006	1.040 ±0.002
	July 3–9, 1934	Fixed	¼S	C	3	1.8–2.3	0.154	−0.001 ±0.005	0.154	+0.044 ±0.021	1.027 ±0.001
	July 4–10, 1934	Moving	¼S	C	3		0.005	−0.001 ±0.001	0.009	−0.008 ±0.008	1.039 ±0.005
III	Jan. 23–24, 1935	Fixed	S	A	2	4.0–4.7	0.022	−0.004 ±0.022	0.056	+0.057 ±0.005	1.059 ±0.001‡
	Jan. 15–25, 1935	Moving	S	A	4	4.0–5.2	0.020	−0.005 ±0.007	0.035	+0.028 ±0.013	1.052 ±0.018‡
	Feb. 6–18, 1935	Fixed	S	A	3	3.6–4.6	0.015	−0.012 ±0.008	0.054	−0.023 ±0.046	1.034 ±0.004
	Feb. 7–15, 1935	Moving	S	A	3	3.9–4.5	0.020	−0.011 ±0.010	0.038	−0.008 ±0.030	1.028 ±0.005

Mean $\rho e/m$ (fixed coil) = 1.037 ± 0.005 Mean $\rho e/m$ (moving coil) = 1.044 ± 0.004 Mean $\rho e/m$ = 1.040

* For the 1933–34 observations. † For the 1935 observations.

‡ These sets were made with the earth's vertical intensity doubled; the others, with all components annulled, as usual. In Group I the mean values of the minimum, or quadrature, double amplitude were 0.40 cm. and 0.37 cm. for the fixed coil and moving coil arrangements respectively.

their usual position in a certain way, as they doubtless were during the changes above referred to, a partial short-circuit occurred. The mutual inductance balance, made not long before these observations began, was not repeated, or the source of the trouble would probably have been found much earlier.

With the new torque and quadrature coil systems in position, and with the new induction solenoid and its compensator, both wound on ebonite, replacing the corresponding coils wound on bakelite, the mutual inductance was again adjusted to zero, and remained unchanged (to at least 1 part in several thousand) when again tested on July 16. Within this interval, from June 19 to July 10, further observations of the same kind as before were made. The results of the 14 sets are given in Group II of the same table, and are essentially identical with those of the first group although currents equal to 1, ½, and 1/4 times that previously employed were used.

For the persistent small difference between the values of ρ resulting from the two experimental methods in Groups I and II, the only explanation found is the possible presence of the error discussed in § 21, B (1) in the fixed coil measurements. The attempt has of course been made to explain it by an insulation defect, as above, but the mutual inductance tests and the absolute values are both decidedly against such an explanation.

Still another series of observations on the same rotor was begun on January 15, 1935, after the primary coils had been rewound with additional precautions for insulation. The mutual inductance was first compensated with precision as before; and it remained compensated, with negligible error, throughout the series. The results are given in Group III of the table already referred to. Here there is a difference of 0.6–0.7 per cent between the two sets of results, ρ being *greater* for the fixed coil, instead of *less*, as in the earlier work. This is quite consistent with the other results as the sign and magnitude of the error mentioned above depend on the symmetry of the rotor and the way it is mounted.

The mean value of $\rho e/m$ for all of these 47 sets is close to the mean value obtained for permalloy earlier. The value obtained with the moving coil is identical with that of Table 5.

Many additional observations made later on permalloy, iron, nickel, cobalt-iron, and cobalt, as will appear below, have likewise shown only small differences between the results with the two arrangements. In general they are entirely unsystematic, and appear to be no greater than those between different groups with the same arrangement. On this account results obtained with the two arrangements have usually been given the same weight, though the error of § 21, B (1) is not present when the moving coil is used. It may account for the large discrepancies between certain of the results for pure cobalt (See p. 434).

§ 39. ADDITIONAL OBSERVATIONS WITH THE 2.4 MM. PERMALLOY. In 1937 three brief series of observations were made with the same rod under different conditions. The results are given in Table 7. For series I the rotor was unmodified, but mounted with different lower suspension and mirror-holder, No. 4.

For series II it was mounted with the short holder No. 5. Although in this series the rotor behaved excellently, and showed very slight asymmetry of any sort, faint striations appeared in the first 6 sets. It seemed impossible that these could be due to such causes as usually produce

TABLE 7

2.4 MM. PERMALLOY. FIXED AND MOVING COILS. 1937. $H = S$

SERIES I. MMH. NO. 4; T.C.E.; $\nu = 18.5$. $2A_\infty = 2.1$–3.6 CM.; QUADRATURE COIL OUT

Date	Mag. Coil	E–W			I–II			$\rho e/m$
		I	II	Mean	E	W	Mean	
May 26	Fixed	−0.058	+0.060	+0.001	−0.180	−0.062	−0.121	1.024
May 27	Moving	+0.041	−0.058	−0.008	+0.455	+0.356	+0.406	1.021

Mean $\rho e/m = 1.022 \pm 0.002$

SERIES II. MMH. NO. 5; T.C.E.; $\nu = 10.5$; QUADRATURE COIL OUT

Date	E–W			I–II			Fixed Coil	Moving Coil	Double Amplitude
	I	II	Mean	E	W	Mean			
July 10	+0.018	+0.028	+0.023	−0.003	+0.007	+0.002	1.059		
July 12	+0.003	+0.006	+0.004	+0.002	+0.005	+0.004		1.056	
July 13	+0.010	+0.002	+0.006	+0.008	0.000	+0.004		1.058	4.4–6.0 cm.
July 14	−0.001	+0.005	+0.002	−0.005	+0.001	−0.002	1.052		
July 15	+0.008	+0.014	+0.011	−0.008	−0.002	−0.005	1.052		
July 16	+0.001	+0.002	+0.002	0.000	+0.001	0.000		1.049	
							Mean 1.054	Mean 1.054	
July 20*(1)	−0.010	+0.010	0.000	−0.004	+0.015	+0.006	1.055+		6.7–7.0 cm.
July 20*(2)	−0.018	+0.003	−0.008	−0.016	+0.005	−0.006	1.052+		

$|\text{E–W}| = 0.009$; $\overline{\text{E–W}} = +0.005$. $|\text{I–II}| = 0.005$; $\overline{\text{I–II}} = 0.000$. Mean $\rho e/m = 1.054 \pm 0.003$

* After removal of spiral leads.

SERIES III. MMH. NO. 6; T.C.E.; $\nu = 11.5$; $2A_\infty = 0.9$–1.7 cm.

QUADRATURE COIL IN, BUT $\overline{Q}/G = -0.002$ ONLY. FIXED COIL

Date Oct. 19	E–W			I–II			$\rho e/m$
	I	II	Mean	E	W	Mean	
(1)	+0.139	−0.165	−0.013	+0.417	+0.013	+0.215	1.058
(2)	+0.162	−0.262	−0.050	+0.376	−0.048	+0.164	1.051

$|\text{E–W}| = 0.182$; $\overline{\text{E–W}} = -0.032$. $|\text{I–II}| = 0.213$; $\overline{\text{I–II}} = +0.190$. Mean $\rho e/m = 1.054 \pm 0.004$

striations, and they were soon traced to the leads, which had been formed into a spiral of unusually large diameter the last time the rotor was rewound. When the leads were cut off and removed the striations completely disappeared. As the results show, the value of ρ was unaffected.

For series III the ends of the rotor were removed and replaced with the threaded flanges for the rigid attachment of the mirror holder. Holder No. 6, whose flanges did not have parallel surfaces, was used. This doubtless accounts for the large asymmetry and the small amplitude.

For reasons not apparent, series I gives a lower value of ρ, the other two series a higher value, than usually obtained with this rotor. The mean differs but slightly from that previously obtained.

§ 40. THE 3.2 MM. PERMALLOY ROTOR. Three groups of observations were made on this rotor. The results of the first group, which seems much the best, are given in Table 8. As used for this group, the rotor was of the standard long type, and was wound with four layers of wire, which the magnetizing current traversed. The mean value of $\rho e/m$ for this group was inserted in III while in the press.

For the second group of observations, Table 9 and Figure 6, the rotor was cut off, restraightened, and rewound with 2 layers of wire, to make a standard short wound rotor like the 2.4 mm. permalloy. The group can hardly be considered as reliable as the others because there were too many variables present. In the figure the apparent value of $\rho e/m$ is plotted against the quadrature coil torque necessary to reduce the quadrature amplitudes to approximately zero. There is marked dependence of $\rho e/m$ on the torque. There is no apparent dependence on the vertical compensation.

For the third group of observations, the rotor was unwound, straightened, and provided with

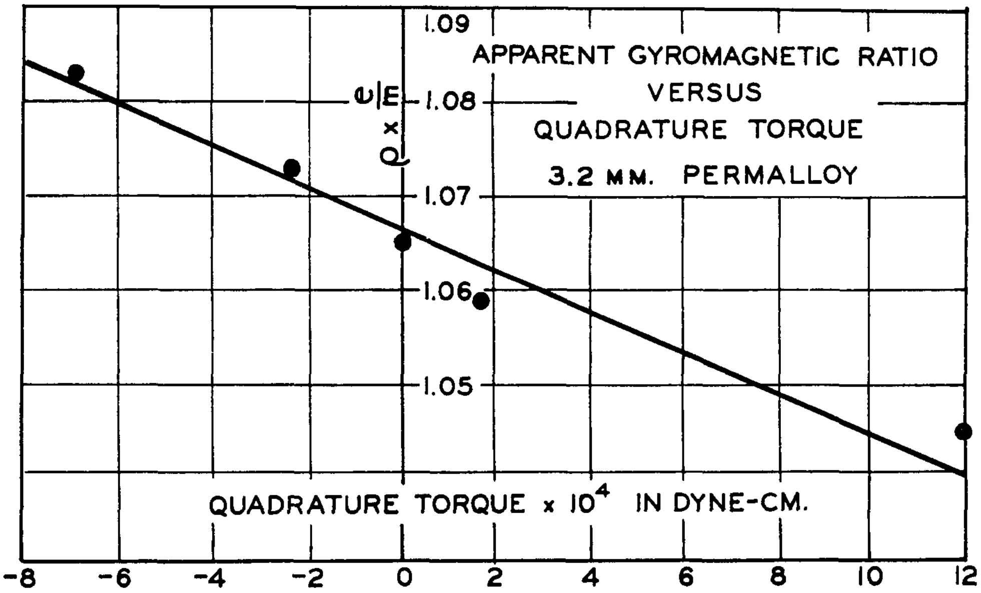

FIGURE 6.

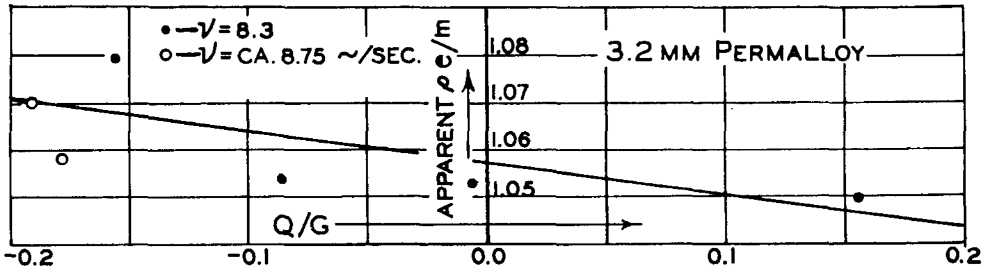

FIGURE 7. Apparent gyromagnetic ratio for 3.2 mm. Permalloy *versus* quadrature torque.

the upper and lower terminals with screws and flanges, and was used with holders No. 6 (Series I) and 7 (Series II). The results are given in Table 10 and Fig. 7. Although the departures from the mean line of the graph are greater than in the case of the second group, the result 1.058 for $\rho e/m$ is probably much more trustworthy than the larger value obtained in that group.

TABLE 8

Long Wound 3.2 mm. Permalloy. $H = 2S$; $\nu = 19.3$; $\mu = 1719$; $\mu' = 6.7$; $2A_\infty = 4$–7 cm.

T.C.A. MMH. No. 3

Date 1931	E–W			I–II			$\rho e/m$
	I	II	Mean	E	W	Mean	
March 5	+0.030	−0.009	+0.010	+0.038	−0.001	+0.018	1.046
March 10	+0.110	+0.030	+0.070	+0.085	+0.005	+0.045	1.050
March 11	+0.057	+0.081	+0.069	+0.010	+0.034	+0.022	1.038
March 12	+0.052	+0.043	+0.048	−0.030	−0.039	−0.034	1.034
March 13	−0.010	−0.006	−0.008	+0.012	+0.016	+0.014	1.037
March 14	+0.033	−0.020	+0.006	+0.012	−0.041	−0.014	1.040
March 18	+0.008	+0.018	+0.013	+0.008	+0.018	+0.013	1.033*
March 21	−0.037	−0.110	−0.074	+0.205	+0.132	+0.168	1.047†
Apr. 3	+0.085	−0.068	+0.008	+0.044	−0.109	−0.032	1.064*
Apr. 4	——	——	——	——	——	——	1.030†

$|\overline{\text{E–W}}| = 0.090$. $\overline{\text{E–W}} = +0.016$. $|\overline{\text{I–II}}| = 0.047$. $\overline{\text{I–II}} = +0.022$. Mean $\rho e/m = 1.042 \pm 0.007$

* Earth's vertical intensity under-compensated by ca. 1 part in 94.

† Earth's vertical intensity over-compensated by ca. 1 part in 94.

TABLE 9

Short Wound 3.2 mm. Permalloy

$H = S$; $\nu = 18.8$; μ (moving coil) $= 1058$; $\mu' = 2.8$; μ (fixed coil) $= 1095$. $2A_\infty = 4.3$–7.7 cm.

T.C.E. MMH. No. 5

Date 1937	Mag. Coil	E–W			I–II			*Current in Z Compensator	$\overline{Q}/G$	Apparent $\rho e/m$
		I	II	Mean	E	W	Mean			
July 1	Fixed	+0.080	+0.088	+0.084	+0.005	+0.013	+0.009	92.7 div.	−0.034	1.073
July 2	Moving	+0.066	+0.087	+0.076	−0.008	+0.013	+0.002	85.2	0.000	1.065
July 3	Fixed	−0.255	−0.214	−0.234	−0.004	+0.037	+0.016	85.2	+0.170	1.044
July 6	Moving	+0.038	−0.035	+0.002	+0.014	−0.059	−0.022	94.5	−0.098	1.082
July 7	Fixed	+0.017	+0.108	+0.062	−0.042	+0.049	+0.004	102.7	+0.025	1.059

$|\overline{\text{E–W}}| = 0.099$; $\overline{\text{E–W}} = -0.002$. $|\overline{\text{I–II}}| = 0.024$; $\overline{\text{I–II}} = +0.022$. Mean $\rho e/m$ (See Fig. 6) $= 1.066 \pm 0.003$

* The vertical or Z component of the earth's magnetic intensity was compensated for a current of about 94 divisions.

§ 41. The Long Wound 2.0 mm. Permalloy Rotor.* This rotor was of the standard long type, and was wound with 4 layers of No. 40 wire. Five series of observations (44 sets in all) were made, and the results are summarized in Table 11. Half the observations were made with an impressed frequency 3 times that of the rotor, and 5 sets were made with the earth's vertical field doubled in intensity by reversing the compensating current. The mean value of $\rho e/m$ for the 44 sets, is 1.052. No certain differences exist between the results obtained under the different conditions.

The detailed measurements of the amplitudes for one complete set of observations with this rotor are given in Table 1, as an example of Method I.

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* This somehow came into the laboratory as *nickel*, and in V the early observations on it were attributed to that substance. Through some curious coincidences the error was not at once detected; but the magnetic behavior of the material finally convinced me that an error had been made; and this was verified by unwinding the rotor, examining its surface color, and measuring its density.

§ 42. COLLECTED RESULTS FOR PERMALLOY AND WEIGHTED MEAN VALUE OF $\rho e/m$. In Table 12 are collected the mean results for $\rho e/m$ as given in the preceding tables and figures, with the exclusion of Table 3. For each rotor relative weights have been assigned to the different groups (except that in the case of the 2.0 mm.

TABLE 10

3.2 MM. PERMALLOY, SHORT, WITHOUT WINDING. $H = S$. T.C.E. $\mu = 1095$

SERIES I. MMH. No. 6. $2A_\infty = 1.5$–3.7 CM. $\nu = 8.3$

Date 1937	E–W			I–II			$\overline{Q}/G$	Apparent $\rho e/m$
	I	II	Mean	E	W	Mean		
Oct. 25	+0.084	−0.368	−0.142	+0.400	−0.052	+0.174	+0.156	1.050
Oct. 26	+0.144	−0.384	−0.120	+0.217	−0.310	−0.046	−0.156	1.079
Oct. 27	+0.044	−0.210	−0.083	+0.322	+0.068	+0.195	+0.017	1.060
Oct. 28	+0.058	−0.168	−0.055	+0.165	−0.061	+0.052	−0.006	1.053*
Oct. 30	+0.023	−0.261	−0.119	+0.299	+0.015	+0.157	−0.086	1.054*

$|\overline{E-W}| = 0.174$; $\overline{E-W} = -0.104$. $|\overline{I-II}| = 0.191$; $\overline{I-II} = +0.106$

* Graphical method used.

SERIES II. MMH. No. 7. $2A_\infty = 4.0$–5.9 CM.

Date 1937	E–W		I–II		ν	$\overline{Q}/G$	Apparent $\rho e/m$
	I	II	E	W			
Dec. 11	+0.316	−0.255	+0.410	−0.161	8.7	−0.19	1.068
	+0.340	−0.265	+0.405	−0.200			1.071
Dec. 16	+0.527	−0.579	+0.446	−0.660	8.8	−0.18	1.062
	+0.696	−0.617	+0.688	−0.625			1.055
Means	+0.470	−0.429	+0.487	−0.412			1.064±0.005

Mean E–W = +0.020. Mean I-II = +0.038

For the mean value of $\rho e/m$ obtained from I and II, viz. 1.058±0.006, see the chart of Fig. 7.

TABLE 11

2.0 MM. LONG WOUND PERMALLOY. MOVING COIL. MMH. NO. 3. $H = 2S$. $\mu = 638$. $\mu' = 4.4$

Series	Date	T.C.	No. Sets	$2A_\infty$	ν	$\lvert\overline{E-W}\rvert$	$\overline{E-W}$	$\lvert\overline{I-II}\rvert$	$\overline{I-II}$	$\rho e/m$	Notes
I	Dec. 24, 1930–Feb. 21, 1931	A	11	2.5 cm.	10	0.010	−0.004 ±0.004	0.022	−0.009 ±0.020	1.040 ±0.005	Impressed frequency $= 3\nu$
II	Dec. 8, 1931–Jan. 9, 1932	A	11	2	10	0.030	−0.015 ±0.011	0.076	−0.025 ±0.065	1.066 ±0.003	Impressed frequency $= 3\nu$
III	Apr. 17, 1932–May 6, 1932	A	15	6	10.3	0.011	−0.005 ±0.005	0.130	+0.130 ±0.032	1.051 ±0.003	Observations made with the Earth's vertical intensity doubled.
IV	Jan. 6, 1935–Jan. 14, 1935	C	5	4.2–4.8	9.8	0.017	+0.003 ±0.008	0.029	+0.023 ±0.021	1.057 ±0.000	
V	Feb. 24, 26, 1935	A	2	4.0–4.5	10.4	0.014	−0.003 ±0.013	0.049	+0.049 ±0.032	1.046 ±0.010	

Mean $\rho e/m$ (44 sets) = 1.052

rotor a straight mean has been taken), and a mean value for each rotor thus arrived at. If now relative weights 3, 2, 1 are assigned to the 2.4 mm., 2.0 mm., and 3.2 mm., rotors, respectively, the final mean reached* is 1.047 ± 0.004. This result is almost identical with that derived from all the early work summarized in Table 3.

TABLE 12

COLLECTED RESULTS FOR PERMALLOY AND WEIGHTED MEAN VALUE OF $\rho e/m$

Rotor	Table	No. Sets	Relative weight of group	e/m	Average error in group
2.4 mm.	4	26	1	1.048	±0.011
	5	17	2	1.044	3
	6	47	2	1.043	5±
	7 I	2	1	1.022	2
	7 II, III	10	2	1.054	3
	Mean for 2.4 mm.		(weight 3)	1.043	
2.0 mm.	11	44	(weight 2)	1.052	4±
3.2 mm.	8	10	3	1.042	7
	9	5	1	1.066	3
	10	7	2	1.058	6
	Mean for 3.2 mm.		(weight 1)	1.051	
Weighted mean $\rho e/m$ for all =				1.047	±0.004

§ 43. IRON. ARMCO IRON. All the results published in III were for Armco iron. Those obtained prior to November 1929 are summarized in Table 3 above. All of these were made without the systematic reversals for half-cycle asymmetry.

Table 13 summarizes the results of the first series of observations on iron in which these systematic reversals were made; and Table 14 gives further details for the final series on iron published much more briefly in III. In this series the strict time schedule finally established was observed.

For the last five sets of this series the vertical intensity of the earth's magnetic field was not completely compensated, the residual intensity being made to vary from 9.8 parts in 94 in the direction of the earth's intensity to 10.0 parts in 94 in the opposite direction. The results are plotted in Fig. 8, and show distinctly a linear relation between the apparent value of ρ and the departure from compensation.

The mean value of $\rho e/m$ for this complete series differs but little from that of the last.

New measurements have been made on rotors of Armco iron, cold-rolled steel, electrolytic iron, and some iron kindly sent me by Professor Honda.

The results of the new measurements on Armco Iron are given in Table 15. The values of $\rho e/m$ agree closely with those already published. The 2.4 mm. rod used in the earlier work was shortened and mounted in a brass tube and provided with flanges and screw terminals for use with the magnet-mirror holder No. 7 and the short suspensions, as described in §§ 9 and 10. In Group I the quadrature coil was used, but the results, as the table shows, are independent of the quadrature. In Group II the quadrature coil was not used, except as indicated. This is one of the groups in which an effort was made to see whether the apparent value of ρ depended on the method of tuning—by gyromagnetic drive (G), by torque coil drive ($T.C.$), or drive by uncompensated horizontal intensity of the earth's field. No certain difference is apparent.

If we give to the 14 sets of Table 13 the relative weight 1, to the 26 of Table 14 the weight 2, and to each of the groups of Table 15 with 8 and 10 half-sets respectively, the weight 1, we obtain as a final mean for Armco iron $\rho e/m$ = 1.032.

§ 44. COLD-ROLLED STEEL. Only one rotor of this material was investigated. It was cut from one of the rods used in the investigation described in II. It was 3.2 mm. in diameter, of the shorter

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* If the three rotors are given equal weights, the result is 1.049 ± 0.004.

TABLE 13

Results on 2.4 mm. Arco Iron Obtained with large Amplitudes and Approximate Elimination of Effects of Half-Cycle Asymmetry in each Set. $H = S$. $\nu = 10$. T.C.A. MMH. No. 3. Moving Coil

Date	$\overline{\|E-W\|}$	$\overline{E-W}$	$\overline{\|I-II\|}$	$\overline{I-II}$	No. sets	$\rho e/m$
Nov. 1929–Jan. 1930	0.069	+0.022	0.254	+0.084	14	1.035±0.008

TABLE 14

Results on 2.4 mm. Armco Iron Obtained with large Amplitudes and Complete Elimination of Effects of Half-Cycle Asymmetry in each Set.† H = ca. $S/2$–S. T.C.A. MMH. No. 3. $\nu = 10$ Moving Coil

Date 1930	E–W			I–II			H		$Z-Z_0$ (Z_0 = ca 94.2)
	I	II	Mean	E	W	Mean	$\rho e/m$	Gausses	
Jan. 24	+0.016	+0.012	+0.014	−0.036	−0.040	−0.038	1.029	17	0
Jan. 25	+0.032	−0.016	+0.008	+0.008	−0.038	−0.015	1.029	17	0
Jan. 27	+0.010	+0.019	+0.014	−0.029	−0.020	−0.024	1.031	17	0
Jan. 28	−0.007	+0.004	−0.002	−0.015	−0.004	−0.010	1.031	17	0
Jan. 29	+0.008	+0.021	+0.014	+0.022	+0.005	+0.014	1.025	17	0
Jan. 30	+0.019	−0.010	+0.004	+0.040	+0.011	+0.026	1.028	17	0
Feb. 1	−0.058	+0.067	+0.004	−0.128	−0.003	−0.066	1.026	17	0
Feb. 3	+0.020	−0.010	+0.005	−0.049	−0.067	−0.058	1.024	17	0
Feb. 6	+0.051	−0.010	+0.020	−0.022	−0.084	−0.053	1.021	17	0
Feb. 9	+0.005	−0.003	+0.001	+0.013	+0.005	+0.009	1.027	17	0
Feb. 10	+0.006	+0.008	+0.007	−0.014	−0.012	−0.013	1.026	17	0
Feb. 11	−0.026	−0.015	−0.020	−0.038	−0.053	−0.046	1.029	17	0
Feb. 18	+0.023	−0.024	0.000	+0.076	+0.029	+0.052	1.029	25	0
Feb. 21	+0.005	+0.020	+0.012	+0.031	+0.046	+0.038	1.039	25	0
Feb. 22	+0.009	−0.003	+0.003	+0.015	+0.003	+0.009	1.034	25	0
Feb. 27	+0.022	−0.020	+0.001	+0.038	−0.004	+0.017	1.026	25	0
Mar. 9	−0.004	−0.015	−0.010	−0.049	−0.060	−0.054	1.032	12	0
Mar. 12	+0.021	−0.047	−0.013	+0.181	+0.113	+0.147	1.030	12	0
Mar. 15	−0.059	−0.012	−0.036	+0.165	+0.129	+0.147	1.030	12	0
Mar. 17	+0.023	+0.010	+0.016	+0.206	+0.193	+0.200	1.042	12	0
Mar. 18	−0.036	+0.007	−0.014	+0.115	+0.158	+0.136	1.029	12	0
Mar. 21	+0.019	−0.007	+0.006	+0.171	+0.138	+0.154	*1.006	17	+10.0*
Mar. 22	+0.018	+0.009	+0.014	+0.116	+0.143	+0.130	*1.039	17	− 6.2*
Mar. 27	+0.011	−0.025	−0.007	+0.154	+0.118	+0.136	*1.054	17	− 9.8*
Apr. 3	+0.035	+0.019	+0.027	+0.054	+0.100	+0.077	*1.022	17	+ 6.0*
Apr. 5	+0.003	+0.012	+0.008	+0.090	+0.099	+0.094	*1.040	17	− 6.0*

Mean |E–W| = 0.019 Mean |I–II| = 0.068 Mean $\rho e/m$ = 1.032±0.003

Mean E–W = +0.003±0.010 Mean I–II = +0.051±0.071

* See curve, Fig. 8.

† One set, judged to be defective on account of a short-circuit, is not included.

type, and was wound with 2 layers of No. 40 insulated wire. The suspension was of No. 32 German silver wire. The values of A_0 were small, and the quadrature coil was not used. Only one group of observations, consisting of 7 sets, was made. The mean results are given in Table 16.

In at least a part of the work on this rotor the band of light on the scale was faintly striated. When these striations are due to ordinary harmonics, which affect A_∞ and A_2 equally, they do not introduce any error in the determination of ρ. But if they come from magnetostriction, they affect (increase) A_∞ more than A_2, and thus tend to give too large a value of ρ. It is possible that the slight excess of the value of ρ given in Table 16 over that obtained for Armco iron is accounted for in this way; but the striations were very faint (small amplitude), and the difference

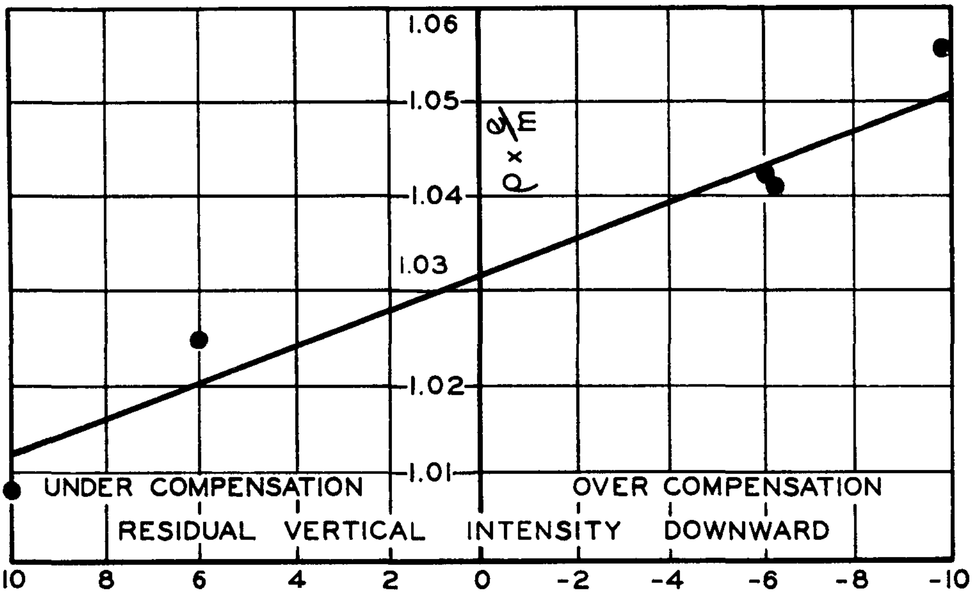

Figure 8. Variation of $\rho e/m$ for Armco Iron rotor with under and over compensation of the vertical intensity of the earth's magnetic field.

TABLE 15

2.4 mm. Armco Iron in Brass Tube. Fixed Coil. $H = S$. T.C.E. MMH. No. 7. $\nu = 6.1$

Group I. With Quadrature Coil

Date 1937	E–W		I–II		$\overline{Q}/G$	$\rho e/m$ (4)	$\rho e/m$ (8)
	I	II	E	W			
Dec. 20*	+0.210	+0.127	+0.069	−0.014	−0.14	1.040	1.026
	+0.190	+0.115	+0.085	+0.010			1.054
Dec. 23	+0.345	+0.151	+0.070	−0.124	+0.02	1.046	1.047
	+0.430	+0.202	+0.099	−0.129			1.044
Dec. 24	+0.477	+0.066	+0.176	−0.235	−0.10	1.031	1.028
	+0.504	+0.029	+0.215	−0.260			1.034
Dec. 28	+0.289	+0.168	+0.091	−0.030	+0.03	1.006	1.005
	+0.316	+0.184	+0.061	−0.071			1.006
Means	+0.345	+0.130	+0.108	−0.106		1.031±0.012	1.031±0.014

* After these observations the rotor was removed to make possible a new calibration of the N–S and E–W coils neutralizing the horizontal component of the earth's magnetic intensity. It was remounted in the same way for the following observations.

TABLE 15—*Continued*

GROUP II. WITHOUT QUADRATURE COIL*

Date 1938	E-W		I-II		(8)	(4)	Tuning
	I	II	E	W			
Jan. 19	−0.143	+0.161	−0.436	−0.132	1.033	1.030	T. C.
	−0.157	+0.165	−0.441	−0.119	1.027		
Jan. 24	+0.045	−0.123	−0.453	−0.621	1.036	1.036	G and X
	+0.068	−0.144	−0.415	−0.627	1.035		
Jan. 26	−0.028	−0.008	−0.470	−0.450	1.038	1.038	G
	−0.025	−0.005	−0.464	−0.444	1.038		
Jan. 27	−0.168	+0.117	−0.504	−0.219	1.022	1.020	T. C.
	−0.164	+0.111	−0.486	−0.211	1.018		
Jan. 28	−0.057	−0.046	+0.198	+0.209	1.034	1.034	G
	−0.054	−0.045	+0.148	+0.157	1.033		
					Mean $\rho e/m$		
	$\lvert E\text{–}W\rvert_{I} = 0.091$		$\lvert I\text{–}II\rvert_{E} = 0.402$		1.032	1.032	
	$\lvert E\text{–}W\rvert_{II} = 0.092$		$\lvert I\text{–}II\rvert_{W} = 0.319$		±0.005	±0.005	

* Except that the quadrature coil was used in finding the conductance for the minimum amplitude.

TABLE 16

3.2 MM. COLD-ROLLED STEEL. MOVING COIL

$\nu = 9.0$. MMH. No. 3. $\mu =$ ca 1220; $\mu' = 2.5$, e.m.u. T.C.A. MMH. No. 3

Date	$2 \times A_\infty$	$2 \times A_0$	E-W			I-II			$\rho e/m$
1935	approx.		I	II	Mean	E	W	Mean	
July 28	6.4–6.7	0.29	−0.005	−0.007	−0.006	−0.053	−0.055	−0.054	1.059
August 12	5.4–5.6	0.39	−0.001	0.000	0.000	+0.031	+0.030	+0.030	1.043
August 14	5.6–5.9	0.64	−0.024	+0.015	−0.005	−0.054	−0.015	−0.034	1.009
August 15	5.6–5.8	0.15	−0.016	+0.007	−0.004	+0.010	+0.033	+0.022	1.046
August 18	5.7–5.9	0.24	+0.007	−0.003	+0.002	+0.039	+0.029	+0.034	1.038
August 23	5.6–5.9	0.60	−0.015	+0.018	+0.001	−0.043	−0.010	−0.026	1.038
August 24	5.4–5.8	0.24	−0.002	0.000	−0.001	−0.054	−0.053	−0.054	1.042

Mean $\lvert E\text{–}W\rvert = 0.009$ Mean E–W $= -0.002$ Mean $\lvert I\text{–}II\rvert = 0.020$ Mean I–II $= -0.012$

Mean $\rho/em = 1.039 \pm 0.009$

may be significant. In II the value of ρ for cold-rolled steel was distinctly greater than that for Armco and Norway iron.

§ 45. HONDA'S IRON. The rotor of Professor Honda's iron is referred to in V, p. 134, footnote. In its first form it was of the complex type (the magnetic material being mounted inside a brass tube, with center fixed and the ends free to slide) and was designated as Iron *C*. The iron rod was 2.0 mm. in diameter, and was turned down from a thicker rod composed of several single crystals. The brass tube was wound with four layers of No. 40 silk-enamel wire. The rotor was exceedingly difficult to work with, the in-phase and quadrature disturbing torques being very troublesome. In 1932 and 1933 three groups of observations were made on this rotor. The mean results are given in the first three lines of Table 17. The quadrature coil was used to reduce the residual amplitudes down nearly to zero. While these observations were in progress, a number of serious accidents occurred to the rotor, and it had to be repaired and remounted repeatedly. Partly as a result of this the values of A_0 (before they were reduced by the quadrature coil) were quite different in different cases and it was practicable to extrapolate from the different values of $\overline{Q}$ for the true value of $\rho e/m$. In the case of the first group the value of ρ was independent of $\overline{Q}$; but in the others, in spite of the low frequency, the dependence was quite marked.

The rotor was later modified. The rod was removed from the brass tube and out of it a standard short wound rotor was constructed. This worked so poorly that it was given up, and a new rotor of the wound complex type, but of the length of the short rotors, was constructed. The brass tube was wound with two layers of No. 40 wire. This rotor worked very well, although the amplitudes were small. The mean results are given in line 4 of Table 17. The quadrature effects were very small and the quadrature coil was not used.

The rod was later removed from the brass tube and out of it a standard short unwound rotor was constructed. Two short groups of observations were made, and the results are given in the last two lines of Table 17. Between these two groups the torque and quadrature coils were rewound and impregnated with natural ceresin wax and the insulation between primary and secondary circuits was all gone over and improved where possible by the substitution of natural ceresin wax for that used formerly. The quadrature coils were used in both series.

The mean value of $\rho e/m$ for all these observations is identical with that obtained with Armco iron. No explanation has been found for the low value resulting from the apparently excellent observations reported in the fourth line of the table.

§ 46. Electrolytic Iron. The rotor of electrolytic iron, as at first used, was similar in dimensions, winding, and mounting to that of cold-rolled steel. It was cut from the Electrolytic iron II used in the investigation described in II. Two groups of observations were made on this rotor, unaltered, in 1934 and 1936. The chief data and the results are given in Table 18. For a third group, made in 1938, the rotor was modified for the short suspensions and for rigid attachment to the magnet-mirror holder No. 7 as explained in §§ 9 and 10. The data and results for this group also are given in Table 18. The band of light in this last group was faintly striated, but so faintly that the striations were observed only with the aid of a lens. The mean value of $\rho e/m$ for the thirteen sets of observations, viz., 1.034, is almost identical with that obtained for Armco iron.

§ 47. Nickel. The earlier results on nickel rotors are summarized in Table 19, which includes the mean asymmetric effects, not published in V.

Two series of observations have since been made on another rotor, of the standard short type, unwound, 2.4 mm. in diameter. The magnetic material, like that of Nickel II, was Boker's *pure nickel* annealed. It was cut from the longer rod from which a rotor of the standard

TABLE 17

Honda 2 mm. Iron. MMH. No. 3

Date	Torque Coil	Mag. Coil	H	μ	μ'	Quad. Coil	No. Sets	ν	$2A_\infty$	$\overline{\lvert \mathrm{E-W} \rvert}$	$\overline{\mathrm{E-W}}$	$\overline{\lvert \mathrm{I-II} \rvert}$	$\overline{\mathrm{I-II}}$	$\rho e/m$
Nov.–Dec. 1932†	B	Moving	2S	907	12	on	9	5.3–5.5	2–5 cm.	0.034	+0.013	0.457	+0.457	1.041 ±0.012*
Jan.–Feb. 1933†	B	Moving	2S	907	12	on	6	5.3	1.4–5.9	0.054	—	0.414	—	1.043 ±0.015**
Mar.–Apr. 1933†	B	Moving	2S	907	12	on	6	5.3	1.1–4.4	0.102	—	0.900	—	1.038 ±0.014**
Dec. 1935–Jan. 1936‡	C	Moving	½S	474	2	off	7	6.0	1.1–1.2	0.016	+0.010	0.016	+0.010	1.002 ±0.010
Mar.–Apr. 1936¶	C	Fixed	S	590	—	on	5	9.0	6–9	0.101	+0.020	0.111	−0.206	1.034 ±0.008**
May 1936¶	D	Fixed	S	560	—	on $\overline{Q}=0$	3	9.3	5–9	0.195	−0.030	0.180	−0.044	1.035 ±0.002††

Mean $\rho e/m$ = 1.032 ±0.010

* ρ independent of $\overline{Q}$

** By extrapolation from ρ–$\overline{Q}$ curve.

† Long rotor in brass tube.

‡ Short rotor in brass tube.

¶ Shortened rotor without tube or winding.

†† Ambiguity in the quadrature coil data makes this result somewhat uncertain. On a different interpretation from that adopted the magnitude would be increased about 1 per cent.

TABLE 18

3.2 MM. ELECTROLYTIC IRON (YENSEN)

μ = ca. 1400; μ' = 2.6, e.m.u. $H = S$

Date	T.C.	MMH.	Mag. Coil	ν	Approx. $2 \times A_{\infty}$	E–W			I–II			$\rho e/m$
						I	II	Mean	E	W	Mean	
Sept. 19, 1934	C	No. 3	Moving	8.9		−0.001	0.000	0.000	−0.018	−0.017	−0.018	1.037
Sept. 21, 1934	C	No. 3	Moving	8.9	6.7	+0.121	+0.132	+0.126	+0.030	+0.041	+0.036	1.033*
Sept. 23, 1934	C	No. 3	Moving	8.9		+0.003	+0.017	+0.010	0.000	+0.014	+0.007	1.033
Sept. 24, 1934	C	No. 3	Moving	8.9		+0.136	+0.149	+0.142	+0.005	+0.018	+0.012	1.032*
Sept. 25, 1934	C	No. 3	Fixed	8.9	to	+0.046	−0.035	+0.006	+0.035	−0.046	−0.006	1.028
Sept. 26, 1934	C	No. 3	Moving	8.9		+0.017	+0.007	+0.012	+0.009	−0.001	+0.004	1.019†
Sept. 27, 1934	C	No. 3	Fixed	8.9		+0.038	−0.050	−0.006	+0.032	−0.056	−0.012	1.025
Sept. 28, 1934	C	No. 3	Moving	8.9	8.4	−0.030	−0.018	−0.024	+0.007	+0.019	+0.013	1.014†
Sept. 29, 1934	C	No. 3	Moving	8.9		+0.025	−0.015	+0.005	+0.023	−0.017	+0.003	1.033
June 30, 1936	D	No. 4	Moving	8.12	6.0	−0.020	−0.019	−0.020	+0.087	+0.046	+0.066	1.048†
July 1, 1936	D	No. 4	Moving	8.12	6.2	−0.008	−0.005	−0.006	+0.032	+0.035	+0.034	1.040†
Jan. 17, 1938	E	No. 7	Fixed	22.6	5.5	+0.006	−0.020	−0.007	+0.046	+0.020	+0.033	1.060
Jan. 18, 1938	E	No. 7	Fixed	22.6	5.6	−0.044	+0.038	−0.003	−0.213	−0.132	−0.172	1.036

Mean |E–W| = 0.027 Mean E–W + 0.020 Mean |I–II| = 0.032 Mean I–II 0.000

Mean $\rho e/m$ = 1.034±0.008

* Quad. Coil used to reduce A_0. Not used in the other sets except on January 17 and January 18 while determining the resistance at which to measure minimum amplitude.

† Fixed coil in place though not used. For the remaining measurements with the moving coil the fixed coil was removed.

long type, wound, had previously been made. Repeated attempts to obtain satisfactory observations with this earlier rotor failed, probably because of the much greater difficulties encountered in making a longer and wound rotor of soft material symmetrical. The results of the two series of observations on the new rotor are summarized in Table 20, and the chief details for series II are given in Table 21. The quadrature coil was used in both series, but the values of ρ were found to be independent of the quadrature torque.

If we assign equal weights to the observations on Nickel IV and to the observations on Nickel II and Nickel III combined, and if in each group we assign double weight to the later (and better) series, we obtain, as a final mean, $\rho e/m$ = 1.052. The mean result from the new work is practically identical with that obtained earlier.

§ 48. PURE COBALT. After many efforts to secure homogeneous rods of pure cobalt, suitable material was at last obtained through the kindness of Professor C. W. Drury and the Deloro Smelting and Refining Company, who brought

TABLE 19

SUMMARY OF EARLIER RESULTS FOR NICKEL ROTORS

Date—1932	Rotor	T.C.	MMH	No. Sets	ν	$2A_{\infty}$	$\lvert\overline{E-W}\rvert$	$\overline{E-W}$	$\lvert\overline{I-II}\rvert$	$\overline{I-II}$	H	μ	μ'	$\rho e/m$
Mar. 17–Apr. 5	Ni II	A	No. 3	6	12.8	3 cm.	0.055	+0.017	0.422	+0.394	2S	227	2.2	1.041+0.033
Apr. 20–Sept. 19	Ni III	A, B	No. 3	17	5.4	2 cm.	0.037	+0.010	0.352	+0.352	2S	344	12	1.058+0.018

TABLE 20

SUMMARY FOR 2.4 MM. NICKEL ROTOR (Ni IV) WITHOUT WINDING

$H = S$. μ = 327.

Series	Date	MMH	T.C.	ν	$2A_{\infty}$	No. Sets	$\lvert\overline{E-W}\rvert$	$\overline{E-W}$	$\lvert\overline{I-II}\rvert$	$\overline{I-II}$	$\rho e/m$
I	Sept.–Oct. 1936	No. 4	D	8.01	5 cm.	11	0.128	−0.049	0.207	+0.111	1.046 ±0.018
II	Apr.–May 1937	No. 5	E	12.0	3–6	8	0.053	+0.022	0.109	+0.052	1.059 ±0.007

TABLE 21

DETAILS FOR NICKEL IV. SERIES II

Date 1937	E–W			I–II			$\rho e/m$
	I	II	Mean	E	W	Mean	
Apr. 27	+0.027	+0.012	+0.020	+0.278	+0.263	+0.270	1.049
Apr. 28	+0.033	+0.006	+0.020	+0.277	+0.250	+0.264	1.053
May 1	−0.010	−0.010	−0.010	+0.025	+0.025	+0.025	1.064
May 4	+0.076	−0.047	+0.014	+0.070	−0.053	+0.008	1.048
May 5	+0.139	−0.105	+0.017	+0.073	−0.171	−0.049	1.067
May 6	+0.110	−0.010	+0.050	−0.050	−0.170	−0.110	1.058
May 7	+0.031	+0.064	+0.048	−0.009	+0.028	+0.010	1.071
May 8	+0.014	+0.024	+0.019	−0.008	+0.001	−0.004	1.063

$|\overline{\text{E–W}}| = 0.053$; $\overline{\text{E–W}} = +0.022$. $|\overline{\text{I–II}}| = 0.109$; $\overline{\text{I–II}} = +0.052$. Mean $\rho e/m = 1.059 \pm 0.007$

my needs to the attention of the Union Minière du Haut Katanga. Through the generosity of this firm, some small plates of their pure electrolytic cobalt were provided. An examination of some of this material by his high frequency spectroscopic method has convinced my colleague, Professor G. W. Potapenko, that the impurities are less than 0.1 per cent, indicating a considerably higher degree of purity than is claimed by the company. From one of the plates were sawn a number of small rods, which were then welded together and ground by mechanicians of the Astrophysical Shop into an accurate round rod 2 mm. in diameter and of length more than sufficient to make possible the construction of a rotor of either the short or the long type. A rotor of the short type, wound with 4 layers of No. 40 wire, was constructed by Mr. Jung. Annealing did not improve the magnetic character of the material (as would be expected from the known behavior of cobalt). For a current of 100 milliamperes the magnetic moment (cobalt alone) was only about 73 e.m.u., that of the coil about 2.7 e.m.u.

With this rotor observations were started in July, 1934. The mean results of the first five sets are given in Table 22. Only the moving coil arrangement was used.

Throughout this group the quadrature coil was used to cut down the minimum amplitude. Through an accident the mutual inductance of the quadrature-coil-torque coil combination was unbalanced. As shown above and in V, however, this introduces no error. The quadrature torque, however, was very large, and the data obtained do not permit the sure elimination of any possible in-phase (or in-opposition) effect of the quadrature coil. Hence much weight cannot be attached to the results of this group

Attempts to secure even equally good results immediately after the five sets recorded for this group in the table failed on account of the breaking down of the insulation of the fixed magnetizing coil, which during these observations was kept mounted coaxially inside the induction solenoid, and supported the torsion head. A partial short-circuit occurred just where the leads were attached to the terminals of the coil, and gave rise to apparent values of ρ which were much too large.

The second group of observations, made with the fixed magnetizing coil removed, was far superior to the first and nearly perfect. The minimum amplitude all but vanished. The quadrature coil was not used. The results are given in Table 23.

A third brief but successful series, with the rotor unwound and otherwise modified for the

TABLE 22

2 MM. PURE COBALT. SERIES I. MOVING COIL

$H = 2S$: $\nu = 9.6$; MMH. No. 3; T.C.C.; $\mu = 73$; $\mu' = 2.7$; QUAD. COILS IN USE

Date	No. Sets	$2 \times A_\infty$	$\lvert\overline{\text{E–W}}\rvert$	$\overline{\text{E–W}}$	$\lvert\overline{\text{I–II}}\rvert$	$\overline{\text{I–II}}$	$\rho e/m$
July 20–26, 1934	5	0.4–0.6 cm.	0.054	−0.007	0.058	+0.020	1.079±0.016

rigid connection to the magnet-mirror-holder No. 7 and the short suspensions, was obtained in March, 1938. The results are given in Table 24. The frequency was much higher than before, and the sine-wave generator was used. The azimuthal asymmetry and the half-cycle asymmetry were both unusually great, but were eliminated by the reversals always practised in this work.

Between II and III several attempts to obtain further reliable observations failed. In some of them quadrature coil data were inadequate; also, in those made with fixed coil, the error of § 21, 13 (1) was probably very large, ξ/μ being great. The mean for all groups was similar to that for series I–III. The results for two of these groups are given in Fig. 9, where the apparent values of $\rho e/m$ are plotted against the quadrature torques $\overline{Q}$. The mean value for $\overline{Q} = 0$ is 1.08.

If we assign to the series I and III the weights 1 and 4, and to series II the weight 16, we obtain, as a final mean, $\rho e/m$ = 1.090.

§ 49. BELL TELEPHONE COPPER-COBALT. Table 25 contains the chief data and results obtained in 1932 on the complex rotor referred to in V as Cobalt IV. The table gives the asymmetry data, which were not published in V, but omits the (uncompensated) values of A_0 (made

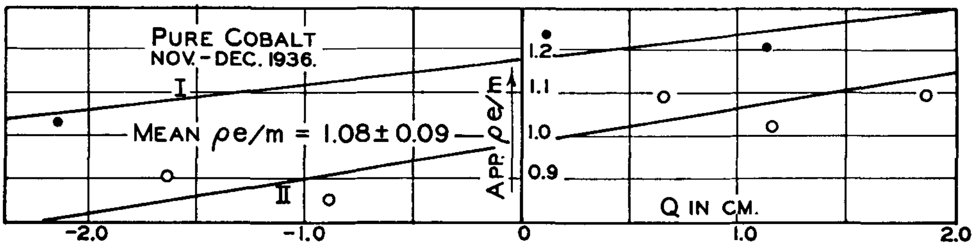

FIGURE 9. Apparent gyromagnetic ratio for Pure Cobalt *vs.* quadrature torque. Full circles represent observations by method I; open circles, by method II. Fixed coil in use.

TABLE 23

2 MM. PURE COBALT. SERIES II. MOVING COIL

$H = 2S$; $\nu = 9.6$; MMH. No. 3; T.C.C.; $\mu = 73$; $\mu' = 2.7$; QUAD. COIL OUT; 5 SETS

Date 1934	2 A_∞ cm.	2 A_0 cm.	E–W			I–II			$\rho e/m$
			I	II	Mean	E	W	Mean	
Sept. 6	0.41–0.47	0.00–0.02	−0.005	+0.034	+0.014	−0.068	−0.029	−0.048	1.097
Sept. 7	0.61–0.64	0.01–0.03	+0.004	+0.018	+0.011	−0.033	−0.019	−0.026	1.093
Sept. 9	0.62–0.63	0.01–0.03	+0.009	+0.002	+0.006	+0.011	+0.004	+0.008	1.092
Sept. 11	0.51–0.55	0.01–0.11	−0.007	+0.035	+0.014	−0.070	−0.028	−0.049	1.096
Sept. 12	0.51–0.62	0.01–0.06	+0.002	−0.010	−0.004	−0.020	−0.032	−0.026	1.090

Means: $|\overline{E-W}|$ = 0.013; $\overline{E-W}$ = + 0.008. $|\overline{I-II}|$ = 0.031; $\overline{I-II}$ = −0.028 Mean $\rho e/m$ = 1.094±0.002

TABLE 24

2 MM. PURE COBALT. SERIES III. FIXED COIL. SINE WAVE GENERATOR

$H = 2S$; μ = ca. 90; MMH. No. 7; T.C.E.; $\nu = 30.8$; QUAD. COIL OUT

Date 1938	2 A_∞	E–W			I–II			$\rho e/m$
		I	II	Mean	E	W	Mean	
March 9 (1)	0.130–0.463	−0.903	+0.635	−0.134	−0.905	+0.633	−0.136	1.071
March 9 (2)	0.132–0.462	−1.032	+0.652	−0.190	−0.922	+0.762	−0.080	1.108
March 12 (1)	0.157–0.430	−0.556	+0.323	−0.116	−0.702	+0.177	−0.262	1.072
March 12 (2)	0.177–0.419	−0.533	+0.422	−0.056	−0.792	−0.163	−0.314	1.054
Means		−0.756	+0.508	−0.124	−0.830	+0.434	−0.198	1.076±0.016

nearly to vanish by the quadrature coil), on which the value of ρ was shown not to depend.

In 1936 a few further observations on this rotor were made, but nothing satisfactory obtained. The rotor showed itself very unsymmetrical in I and II, and the quadrature data were insufficient to interpret. In 1937 the rod was shortened and remounted, in a (shorter) brass tube; but again the quadrature coil data and the disturbances were such as to render a reliable calculation impracticable. With three other rotors, however, successful observations were made.

Table 26 gives the data and results for a standard short rotor 2.4 mm. in diameter, without winding. The quadrature coil was used, and the quadrature torque was nearly constant in magnitude, but small. From experiments made shortly afterward on the Honda iron rotor, with variable quadrature torque and with nearly the same frequency and magnetic moment, it is probable that the quadrature effect on this cobalt rotor did not produce an error greater than ½ per cent.

Table 27 gives the data and results for a standard short rotor, without winding, 3.2 mm. in diameter. The quadrature coil was used, but the maximum value of $\overline{Q}/G$ had a magnitude of only 0.15, and the apparent values of ρ were found to be independent of $\overline{Q}$ as the table shows.

Table 28 gives the results on another 2.4 mm. rotor, mounted in a brass tube, new short style, for use with rigidly connected magnet-mirror holders Nos. 6 and 7 and the short suspensions. $\overline{Q}/G$ was large, ranging from -0.3 to -0.6, but there is no evidence of any appreciable effect on the value of ρ.

If we assign equal weights to each of the four

TABLE 25

2.4 MM. COPPER-COBALT (LONG) IN BRASS TUBE. MOVING COIL.

$H = 2S$. $\mu = 1115$; $\mu' = 12$. $\nu = 5.5$. MMH. No. 3. T.C.B. $2A_\infty = 4.5$ CM. ±

Date 1932	E–W			I–II			$\rho e/m$
	I	II	Mean	E	W	Mean	
June 27	−0.100	−0.077	−0.088	+0.150	+0.174	+0.162	1.113*
June 28	−0.055	+0.020	−0.018	−0.004	+0.071	+0.034	1.077
June 29	−0.020	−0.032	−0.026	+0.351	+0.339	+0.345	1.063
July 5	−0.089	−0.035	−0.062	+0.216	+0.270	+0.243	1.060
July 6	−0.048	−0.041	−0.044	+0.360	+0.367	+0.364	1.076
July 11	−0.082	+0.013	−0.034	+0.030	+0.125	+0.078	1.070
July 12	−0.012	−0.074	−0.043	+0.055	−0.007	+0.024	1.059
July 14	−0.037	−0.045	−0.041	+0.163	+0.155	+0.159	1.064
July 16	−0.039	−0.063	−0.051	+0.127	+0.103	+0.115	1.077
July 19	−0.034	−0.035	−0.034	+0.233	+0.232	+0.232	1.074
July 20	+0.026	+0.064	+0.045	+0.080	+0.118	+0.099	1.070
July 27	0.000	−0.032	−0.016	+0.247	+0.215	+0.231	1.065
Aug. 4	−0.047	−0.065	−0.056	+0.120	+0.106	+0.113	1.075

Mean |E–W| = 0.045. Mean E–W = −0.036 Mean |I–II| = 0.170. Mean I–II = +0.169 Mean $\rho e/m$ = 1.073±0.009

* Adjustments of rotor and torque coil much improved after this set.

TABLE 26

2.4 MM. COPPER-COBALT (SHORT) WITHOUT WINDING

Date 1936	E–W			I–II			$\rho e/m$	Other Data $2A_\infty = 5$–8 cm.
	I	II	Mean	E	W	Mean		
March 9	+0.017	−0.080	−0.032	+0.261	+0.164	+0.212	1.100	MMH. No. 4
March 11	+0.032	−0.122	−0.045	+0.347	+0.193	+0.270	1.090	T.C.C.
March 13	+0.060	−0.025	+0.018	+0.259	+0.174	+0.216	1.070	$\nu = 7.9$ ∼/sec
March 14	−0.036	−0.057	−0.046	+0.278	+0.274	+0.276	1.112	$\mu = 486$ e.m.u.

$|\overline{E-W}| = 0.054$; $\overline{E-W} = -0.026$. $|\overline{I-II}| = 0.244$; $\overline{I-II} = +0.244$. Mean $\rho e/m = 1.087 \pm 0.013$

TABLE 27

3.2 mm. Copper-Cobalt (Short) Without Winding

$H = S$. $\mu = 679$. $\nu = 14.5$. T.C.E. MMH. No. 4

Date 1937	E-W			I-II			$\overline{Q}/G$	$\rho e/m$
	I	II	Mean	E	W	Mean		
May 17	+0.046	−0.249	−0.102	+0.844	+0.549	+0.696	−0.15	1.079
May 18	+0.251	−0.232	+0.010	+0.950	+0.467	+0.708	−0.01	1.096
May 19	−0.067	−0.008	−0.038	−0.131	−0.072	−0.102	−0.02	1.080
May 20	+0.138	−0.175	−0.018	+0.030	−0.283	−0.126	−0.01	1.096
May 21	−0.388	+0.250	−0.069	−0.005	+0.633	+0.314	−0.07	1.100
May 22	−0.390	+0.400	+0.005	−0.159	+0.631	+0.236	−0.08	1.123

$|\overline{E\text{-}W}| = 0.216$; $\overline{E\text{-}W} = -0.035$. $|\overline{I\text{-}II}| = 0.396$; $\overline{I\text{-}II} = +0.288$. Mean $\rho e/m = 1.096 \pm 0.011$

TABLE 28

2.4 mm. Copper-Cobalt in Brass Tube, Short, Without Winding

$H = S$. $\mu = 486 \pm$*. $\nu = 7.1$. T.C.E. MMH. No. 6

Date 1937	E-W			I-II			$\overline{Q}/G$	$\rho e/m$ (8)	$\rho e/m$ (4)
	I	II	Mean	E	W	Mean			
Nov. 22	−0.204	−0.127		−0.391	−0.304		−0.4	1.076	1.090
	−0.297	−0.107		−0.412	−0.222			1.105	
Nov. 23	−0.078	−0.212		−0.355	−0.489		−0.4	1.071	1.081
	−0.123	−0.228		−0.346	−0.451			1.091	
Nov. 24	−0.156	−0.124		−0.372	−0.340		−0.6	1.035	1.041
	−0.290	−0.047		−0.379	−0.136			1.047	
Nov. 27	−0.144	−0.226		−0.561	−0.643		−0.3	1.085	1.079
	−0.098	−0.136		−0.530	−0.568			1.073	
Means	−0.174	−0.151	−0.162	−0.418	−0.394	−0.406	−0.42	1.073±0.016	1.073±0.016

* The moment of this rotor was not measured, but the rod was of the same material and dimensions as that of Table 26, and must have had nearly the same moment.

groups of observations in Tables 25–28, we obtain as a final mean, $\rho e/m = 1.082$.

§ 50. Cobalt-Iron. This rotor was at first of the standard short type. The magnetic material was 3.2 mm. in diameter, and was cut from the cobalt-iron (Preuss's alloy) compensator used in the investigation of II. It was wound with four layers of No. 40 wire, and provided with an upper suspension of No. 34 German silver wire. The first two series of observations were obtained in 1934 and 1936. Both were apparently excellent. The quadrature coil was not needed in either series. The chief data and results are contained in Table 29.

In the first series (1934) only the moving coil arrangement was used. The amplitudes were inconveniently large with the standard current of 100 milliamperes, so that all but the first set of observations were obtained with a current of one half that magnitude (corresponding to an impressed magnetic intensity of $H = S$). In the second series (1936) both moving and fixed coil arrangements were used, and six sets were made by Method II.

With the standard method, no difference appears between the results obtained by the fixed and moving coil arrangements. With Method II, which is less reliable, there is a difference of 1.8 per cent, which is far larger than the apparent error.

The inexplicable discrepancy of about 3 per cent between the results of the series I and II led to series III and IV, the chief data and results for which are given in Tables 30 and 31 and Fig. 10, I.

No certain difference is indicated between the results for fixed coil and moving coil methods. But series III and the last part of series IV, made

TABLE 29

3.2 MM. COBALT-IRON, SERIES I (1934) AND SERIES II (1936). WITHOUT QUADRATURE COIL

Date	T.C.	MMH	ν	H	μ	μ'	$2A_\infty$	$2A_0$	Mag. coil	$\|E-W\|$	$\overline{E-W}$	$\|I-II\|$	$\overline{I-II}$	No. Sets	$\rho e/m$
1934 Nov. 23–29	C	No. 3	3.16	S 2S	1158 1636	2.8 5.6	8.7–9.4 11.5–13.9	0.2–4.1 0.3–1.1	Moving	0.015	+0.001	0.034	−0.018	5	1.008 ±0.006
1936 May 19–June 16	D	No. 4	4.54	S	1274		4.2–4.9	0.0 to 0.3	Fixed	0.024	−0.011	0.024	+0.018	5	1.040 ±0.009
1936 May 23–June 18	D	No. 4	4.54	S	1158	2.8	3.6–4.8		Moving	0.026	−0.022	0.024	−0.008	6	1.038 ±0.006
1936 May 28–June 3	D	No. 4	4.54	S	1256 and 1264		4.2–4.8		Fixed	0.026	+0.024	0.012	+0.005	2*	1.048 ±0.002
1936 May 29–June 8	D	No. 4	4.54	S	1184	2.8	4.0–4.7		Moving	0.027	−0.024	0.012	−0.010	4*	1.030 ±0.006

Mean $\rho e/m = 1.032$

* Observations made by Method II.

TABLE 30

3.2 MM. COBALT-IRON, SERIES III, WITHOUT QUADRATURE COIL

$H = S$. MMH. No. 4. T.C.E. $\nu = 13.8$. $2A_\infty = 4.7$–8.1, $2A_0 = 0.1$–1.6

Magnetizing Coil	Date 1937	E-W			I-II			$\rho e/m$
		I	II	Mean	E	W	Mean	
Fixed	May 29	+0.002	−0.010	−0.004	−0.060	−0.072	−0.066	1.002
	June 1	−0.042	−0.008	−0.025	−0.041	−0.107	−0.074	0.995
	June 4	+0.008	+0.001	−0.004	−0.077	−0.084	−0.080	1.016*
	June 10	−0.020	+0.026	+0.003	−0.052	−0.006	−0.029	1.019
	June 12	−0.048	+0.037	−0.006	−0.086	−0.001	−0.044	1.020

Mean $|E-W| = 0.020$ Mean $E-W = +0.009$ Mean $|I-II| = 0.059$ Mean $I-II = -0.059$
Mean $\rho e/m = 1.010 \pm 0.005$

Magnetizing Coil	Date 1937	E-W I	E-W II	E-W Mean	I-II E	I-II W	I-II Mean	$\rho e/m$
Moving	May 31	+0.028	+0.010	−0.018	+0.020	+0.002	+0.011	1.015
	June 3	+0.013	−0.016	+0.029	+0.033	+0.004	+0.018	1.020
	June 9	+0.013	+0.002	+0.011	+0.077	+0.066	+0.072	1.033
	June 11	−0.001	−0.003	+0.002	+0.038	−0.003	+0.018	1.002

$|\overline{E-W}| = 0.011$ $\overline{E-W} = +0.006$ $|\overline{I-II}| = 0.030$ $\overline{I-II} = +0.030$ Mean $\rho e/m = 1.018 \pm 0.009$

* During this set the coils of the mutual inductance compensator were both short circuited. Proper allowance was made for this in the calculations.

with the long magnet-mirror holder and at nearly the same frequency (ca. 14 cycles per second) agree almost exactly, with $\rho e/m = 1.014$ and 1.010; while the first part of series IV, made with a short holder and at a much lower frequency, gives 1.038. In series IV there is no dependence on quadrature in the case of the low frequency work, while $\overline{Q}/G$ happened to be negligible with the rotor as mounted for the higher frequency.

No explanation of the differences between the values of ρ being apparent, another series of observations was made, viz., series V, for which the results are given in Table 32, and Fig. 10, Curve II. For this series the cobalt-iron rod was mounted in a brass tube and provided with the proper terminals for rigid attachment to the magnet-mirror holder No. 7 and to the short suspensions. There is a marked dependence on the quadrature torque, the mean value of $\rho e/m$ (corresponding to $\overline{Q} = 0$) being 1.020.

If we assign to the 22 sets of series I and II and to the 23 sets of series III–V equal weights,

TABLE 31

3.2 MM. COBALT-IRON, SERIES IV, WITH QUADRATURE COIL

$H = S$. T.C.E. $2A_{\infty}$ = 6.4–10.5 (Aug. 1–7); 4.4–7.0 (Aug. 26–31)

Date 1937	Mag.-Coil	Mirror Holder	Frequency cycles	E–W		I–II		$\bar{Q}/G$	Apparent $\rho e/m$
				I	II	E	W		
Aug. 1 (1)	Fixed	No. 5	5.1 sec.	−0.047	+0.139	−0.159	+0.027	+0.037	1.038
Aug. 1 (2)	Fixed	No. 5	5.1	−0.062	+0.154	−0.157	+0.059		1.042
Aug. 5 (1)	Fixed	No. 5	5.1	+0.093	+0.027	+0.078	+0.012	+0.116	1.042
Aug. 5 (2)	Fixed	No. 5	5.1	+0.101	+0.020	+0.096	+0.015		1.037
Aug. 6 (1)	Moving	No. 5	5.1	+0.038	+0.043	−0.019	−0.016	−0.085	1.039
Aug. 6 (2)	Moving	No. 5	5.1	+0.036	+0.037	−0.020	−0.019		1.039
Aug. 7 (1)	Moving	No. 5	5.1	+0.047	+0.040	−0.008	−0.015	+0.021	1.035
Aug. 7 (2)	Moving	No. 5	5.1	+0.040	+0.041	−0.013	−0.012		1.035
Aug. 26 (1)	Fixed	No. 4	14.2	−0.105	+0.030	−0.201	−0.066	Negligible	0.999
Aug. 26 (2)	Fixed	No. 4	14.2	−0.095	+0.038	−0.211	−0.078		1.003
Aug. 30 (1)	Fixed	No. 4	14.2	−0.085	+0.045	−0.104	+0.026		0.993
Aug. 30 (2)	Fixed	No. 4	14.2	−0.085	+0.005	−0.094	−0.004		1.014
Aug. 31 (1)	Moving	No. 4	14.2	−0.012	−0.003	−0.022	−0.013		1.021
Aug. 31 (2)	Moving	No. 4	14.2	−0.034	−0.009	−0.050	−0.025		1.030

Mean $\rho e/m$ for Aug. 1–Aug. 7 = 1.038±0.002. (See Fig. 10, I) Mean $\rho e/m$ for Aug. 26–Aug. 31 = 1.010 ± 0.012

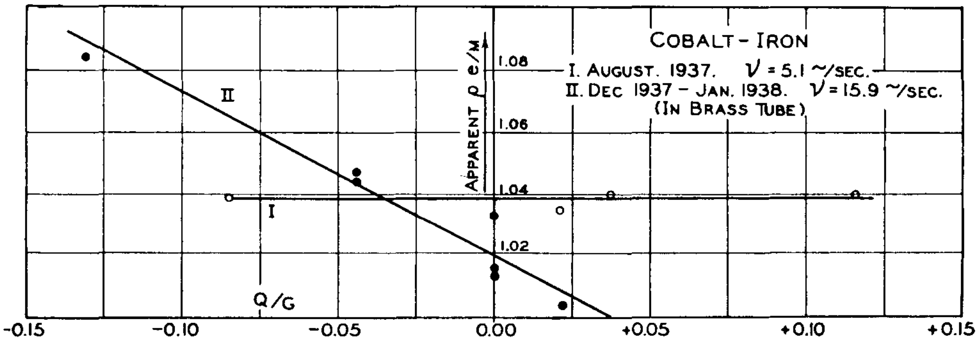

FIGURE 10. Cobalt-Iron. Apparent gyromagnetic ratio *vs.* quadrature coil torque.

and if in the latter group we assign equal weights to series III, series V, and the first division of series IV, and half as much weight to the second half of series IV we obtain, as a final mean, $\rho e/m$ = 1.027.

§ 51. HIPERNIK. Several rods of this material were kindly prepared and sent to me by Dr. Yensen and Mr. Frey of the Westinghouse Electric and Manufacturing Company, for which I am greatly indebted to them and the company. After forging, swaging, and drawing, they had to be annealed in a suspended position with weights attached to the lower ends, a very special heat treatment, in order to insure straightness. Even then the heavier rods did not come out perfectly straight. So they were straightened by a slight stretching and were re-annealed in silica tubes. The material is so soft that it has to be handled with extreme care.*

Two rotors were at first constructed from this material, one of them a standard wound rotor of the longer type 2.4 mm. in diameter, the other a standard unwound short rotor 1.6 mm. in diameter. A number of attempts to secure satisfactory observations with these rotors, especially with the 2.4 mm. rotor, were failures. With this rotor the gyromagnetic ratio was roughly obtained as early as 1928, and agreed within a per cent or two with the precise determinations obtained recently. But the observations were very difficult and rough, apparently on account

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* These statements are quoted almost verbatim from Dr. Yensen.

TABLE 32

3.2 MM. COBALT-IRON, SERIES V (BRASS TUBE WITHOUT WINDING)

$H = S$. T.C.E. MMH. No. 7. $\nu = 15.9$. $A_\infty = 0.5$–3.0

Date	E-W		I-II		Q/G	Apparent $\rho e/m$	
	I	II	E	W		(14)	(7)
December 30, 1937	+1.341	+1.368	−0.036	−0.009	−0.131	1.082	1.084
	+1.253	+1.447	−0.204	−0.010		1.087	
December 31, 1937	+1.299	+1.388	−0.054	+0.035	−0.044	1.046	1.047
	+1.334	+1.360	−0.002	+0.024		1.048	
January 4, 1938	+0.020	+0.069	−0.030	+0.019	0.000	1.042	1.033
	+0.024	+0.024	+0.017	+0.017		1.024	
January 5, 1938	−0.042	+0.049	−0.096	−0.005	0.000	1.025	1.016
	+0.018	+0.074	−0.067	−0.011		1.008	
January 6, 1938	+0.103	+0.028	+0.063	−0.012	0.000	1.016	1.014
	+0.036	+0.082	−0.037	+0.009		1.012	
January 7, 1938	−0.737	−0.608	−0.147	−0.018	−0.044	1.055	1.044
	−0.644	−0.642	−0.127	−0.145		1.034	
January 8, 1938	+0.020	+0.079	−0.076	−0.027	+0.022	1.009	1.004
	−0.005	+0.080	−0.090	−0.005		0.998	

$|E\text{–}W|_I = 0.491$; $|E\text{–}W|_{II} = 0.521$. $|I\text{–}II|_E = 0.075$; $|I\text{–}II|_W = 0.025$. Mean $\rho e/m = 1.020$ (See Fig. 10, II)

of the severe magnetostriction which this material exhibits. The Page effect was exceedingly audible, and the band of light on the scale was badly broken up with the lines due to pseudo-harmonics.

When, however, the 1.6 mm. rotor was remounted in a brass tube in such a manner as to eliminate as far as possible the effects of magnetostriction and was used with the short upper and lower suspensions and the rigidly connected magnet-mirror holder, it behaved most beautifully, and gave the results quoted in Table 33. Magnetically, this rotor was so symmetrical that in the full earth's field the amplitude was not more than two or three times the gyromagnetic amplitude. All quadrature effects were small. The band of light on the scale was perfectly smooth. The magnetic moment of the rotor, as used with a current of 350 milliamperes, was about 370 e.m.u. The quadrature coil was used; but, as the table shows, the values of ρ obtained are independent of $\bar{Q}$.

The mean value obtained for $\rho e/m$ viz., 1.052, does not differ from that for pure nickel.

TABLE 33

1.6 MM. HIPERNIK (YENSEN) IN BRASS TUBE, FIXED COIL

$H = S$. μ = ca. 375. T.C.E. MMH. No. 6. $2A_\infty = 1.07$–1.55 CM.

Date 1937	E-W			I-II			$\rho e/m$ Half Sets	$\rho e/m$ Complete Sets	$\bar{Q}/G$	ν ~/sec.
	I	II	Mean	E	W	Mean				
Oct. 11 (1)	−0.050	+0.038	−0.006	+0.003	+0.091	+0.047	1.058	1.056	+0.127	7.3
Oct. 11 (2)	−0.029	+0.033	+0.002	−0.002	+0.060	+0.029	1.054			
Oct. 12 (1)	−0.003	+0.040	+0.018	−0.139	−0.096	−0.118	1.049	1.044	−0.006	7.3
Oct. 12 (2)	−0.046	+0.089	+0.022	−0.216	−0.081	−0.148	1.040			
Oct. 13 (1)	+0.010	+0.034	+0.022	−0.124	−0.100	−0.112	1.062	1.054	−0.085	7.3
Oct. 13 (2)	+0.030	+0.005	+0.018	−0.072	−0.097	−0.084	1.045			
Oct. 14 (1)	+0.019	+0.003	+0.011	−0.077	−0.093	−0.085	1.060	1.060	+0.036	7.3
Oct. 14 (2)	+0.041	+0.003	+0.022	−0.075	−0.123	−0.099	1.060			
Oct. 15 (1)	+0.074	+0.069	+0.072	−0.038	−0.043	−0.040	1.027	1.046	−0.054	9.2
Oct. 15 (2)	+0.061	+0.101	+0.081	−0.022	+0.018	−0.002	1.065			

$|E\text{–}W| = 0.039$; $\overline{E\text{–}W} = +0.026$. $|I\text{–}II| = 0.079$; $\overline{I\text{–}II} = -0.070$ Mean 1.052 ±0.009 Mean 1.052 ±0.006

§ 52. HOPKINSON'S IRON-NICKEL ALLOY (IRON 75%, NICKEL 24.5%). In 1934 a rotor of this material was constructed. The rotor was of the standard short type, and wound with four layers of No. 40 wire. The magnetic material was 3.2 mm. in diameter, and was cut out of the Hopkinson alloy compensator used in the investigation of II. As explained in II, the material had been properly treated thermally to make it as highly magnetic as practicable. The upper suspension was of No. 32 German silver wire. The quadrature amplitudes were small and it was unnecessary to use the quadrature coil. Eight good sets of observations were obtained. The results are contained in Table 34 under series I. Only the moving coil arrangement was used, with an impressed magnetic field of strength $2S$.

In 1938 the rotor was reconstructed into the new standard short type without winding, and was used with the rigidly attached magnet-mirror holder No. 7 and short suspensions. The magnetic field was somewhat stronger than for series I. The results of the observations, which were so good that it was unnecessary to take many of them, are given in Table 34 under series II.

If we assign to series II the same weight assigned to series I we obtain, as a final mean, $\rho e/m = 1.024$.

§ 53. COBALT-NICKEL. In 1934 a standard short cobalt-nickel rotor was constructed. It was wound with two layers of No. 40 wire and provided with a suspension of No. 32 German silver wire. The magnetic material was 3.2 mm. in diameter, and was cut out of the cobalt-nickel compensator used in the investigation of II. Observations with this rotor were difficult, and magnetostrictive striations were always present in the band of light on the scale. The residual amplitudes A_0 was small, and the quadrature coil was used in only one set of the first series of observations, a summary for which is given in Table 35.

In 1935 work with this rotor was resumed. It was found that the torsion head was cracked,

TABLE 34

3.2 MM. ROTOR OF HOPKINSON'S ALLOY (IRON 75%, NICKEL 25%).

SERIES I, MOVING COIL

$H = 2S$. $\mu = 319$, $\mu' = 5.5$. $\nu = 5.2$. T.C.C. MMH. No. 3. $2A_\infty = 0.9\text{–}1.5$.

$2A_0 < 0.1$ EXCEPT IN FIRST SET

Date 1934	E–W			I–II			$\rho e/m$
	I	II	Mean	E	W	Mean	
Dec. 11	−0.041	+0.031	−0.005	+0.269	+0.341	+0.305	1.005
Dec. 13	+0.106	−0.130	−0.012	+0.342	+0.106	+0.224	1.019
Dec. 14	−0.001	−0.018	−0.010	+0.169	+0.152	+0.160	1.024
Dec. 17	−0.009	−0.042	−0.026	+0.321	+0.288	+0.304	1.031
Dec. 18	−0.031	−0.028	−0.030	+0.286	+0.289	+0.288	1.009
Dec. 19	−0.062	−0.021	−0.042	+0.213	+0.254	+0.234	1.007
Dec. 20	+0.025	+0.032	0.028	+0.244	+0.251	+0.248	1.026

Mean |E–W| = 0.041 Mean |I–II| = 0.252 Mean $\rho e/m$ = 1.017±0.009
Mean E–W = −0.014 Mean I–II = +0.252

SERIES II. WITHOUT WINDING

$H = 2S$. $\mu = 441$. T.C.E. MMH. No. 7. $\nu = 9.9$

Date 1938	$2A_0$	$2A_\infty$	E–W			I–II			$\rho e/m$
			I	II	Mean	E	W	Mean	
April 1	0.065 to 0.135	2.2 to 2.7	−0.256	+0.266	+0.005	−0.264	+0.258	−0.003	1.030
			−0.225	+0.213	−0.006	−0.211	+0.227	+0.008	1.027
April 2	0.170 to 0.375	1.8 to 3.1	−0.504	+0.530	+0.013	−0.539	+0.495	−0.022	1.030
			−0.497	+0.530	+0.016	−0.542	+0.485	−0.028	1.036
Means			−0.370	+0.385	+0.007	−0.389	+0.366	−0.011	1.031±0.003

the insulation had become defective, and the rod had become bent. The rotor was then rewound and otherwise thoroughly repaired, and six more sets of observations obtained. Although the residual amplitudes were small, the quadrature coil was again used. The resulting values of ρ were independent of the magnitude of the quadrature coil torque. A summary of the principal data and results is given in Table 35, and further details in Table 36.

The second series is far superior to the first, but the mean results of the two differ only slightly. In this second series the amplitude of the striation harmonics was so small that the residual double amplitude $2A_0$ could be reduced by the quadrature coil to zero within two or three tenths of a millimeter.

In 1938 the rotor was reconstructed into one of the standard new short unwound rotors in a brass tube with the standard new terminals, and was used with short suspensions and the rigidly attached magnet-mirror holder No. 7. The quadrature coil was not used. Striations, as was to be expected, were entirely absent. The chief data and results are given in Table 37.

This is one of the groups in which an effort was made to see whether any difference in the magnitude of ρ would result from tuning to resonance by torque-coil drive and rotor drive, the two modes of drive being used in this group alternately in complete sets. As the table shows, no appreciable difference was found.

If we give equal weights to the last two series, and half as much to the first series, the mean value of $\rho e/m$ is 1.077.

§ 54. Heusler Alloys. Several attempts have been made to secure reliable observations on Heusler alloys, but so far with limited success. Two rotors were constructed from rods sawn from the large rotor referred to in II as *Heusler alloy 1*. One was of the standard short type, unwound, the other of the short type, unwound, in a brass tube. The material was very porous and the rod of the second rotor was in two pieces, cemented together. In both cases the disturbances were too great for observations of any value.

A number of other rods were cast in vacuo and with the greatest care possible at the Research Laboratory of the General Electric Company

TABLE 35

3.2 mm. Cobalt-Nickel. Summary for Series I and II

Moving Coil. $H = S$. MMH. No. 3. T.C.C. $\nu = 9.0$

Series	Date	No. of Sets	$2A_\infty$	$\lvert\text{E-W}\rvert$	$\overline{\text{E-W}}$	$\lvert\text{I-II}\rvert$	$\overline{\text{I-II}}$	μ	μ'	$\rho e/m$
I	Nov. 7–15, 1934	4	1.4–3.1	0.226	−0.069±0.108	0.328	+0.290±0.288	429	2.6	1.085±0.038
II*	Sept. 27–Oct. 8, 1935	6	2.0–2.9	0.047	+0.045±0.006	0.075	+0.020±0.032	419	2.5	1.077±0.006

* Rotor rewound and restraightened.

TABLE 36

3.2 mm. Cobalt-Nickel. Series II. Detailed Results for $\rho e/m$

Date 1935	E-W			I-II			$\rho e/m$
	I	II	Mean	E	W	Mean	
Sept. 27	+0.004	+0.072	+0.038	0.000	+0.068	+0.034	1.090
Sept. 29	−0.008	+0.088	+0.040	+0.001	+0.097	+0.049	1.073
Oct. 1	+0.028	+0.071	+0.050	+0.045	+0.098	+0.072	1.079
Oct. 5*	+0.072	+0.038	+0.055	+0.005	−0.029	−0.012	1.067
Oct. 7	+0.027	+0.055	+0.041	−0.053	−0.025	−0.039	1.074
Oct. 8	+0.048	+0.057	+0.048	+0.010	+0.019	+0.014	1.078

$|\text{E-W}| = 0.047$; $\overline{\text{E-W}} = +0.045\pm0.006$. $|\text{I-II}| = 0.075$; $\overline{\text{I-II}} = +0.020\pm0.032$; Mean $\rho e/m = 1.077\pm0.006$

* Magnet-mirror holder straightened and reversed in azimuth with regard to the rotor.

TABLE 37

3.2 MM. COBALT-NICKEL. SERIES III. ROTOR IN BRASS TUBE, WITHOUT WINDING

$H = S$. $\mu = 451$. MMH. No. 7. T.C.E. $\nu = 6.2$. $2A_{\infty} = 0.51\text{–}1.62$

Date 1938	E–W		I–II		$\rho e/m$	
	I	II	E	W	(1) Tuning by Torque Coil	(2) Tuning by Rotor
Feb. 16	+0.879	−1.027	+0.810	−1.096	1.085	
	+0.784	−0.949	+0.707	−1.026	1.086	
Feb. 17	+0.713	−0.849	+0.655	−0.907		1.060
	+0.793	−0.817	+0.575	−1.035		1.057
Feb. 18	+0.967	−0.969	+0.711	−1.225	1.073	
	+0.850	−0.926	+0.730	−1.046	1.079	
Feb. 22	+0.897	−0.833	+0.773	−0.957		1.076
	+0.912	−0.803	+0.726	−0.989		1.061
Feb. 23	+0.780	−0.801	+0.646	−0.935	1.065	
	+0.692	−0.689	+0.575	−0.806	1.054	
Feb. 24	+0.636	−0.713	+0.480	−0.869		1.074
	+0.545	−0.642	+0.431	−0.756		1.090
Means	+0.787	−0.835	+0.652	−0.971	(1) 1.074±0.010	(2) 1.070±0.010
Means	−0.024		−0.160		(1) and (2) 1.072±0.010	

through the kindness of Mr. Fuller and Mr. Collins. To them and the Laboratory I am greatly indebted for this service. Some of these rods were of material taken from Heusler alloy I, composed of Al, Mn, and Cu in atomic proportions; some from new materials in the same proportions; some from new materials in the proportions Al, Mn, Cu_2; and some from the same metals in still different proportions with the addition of a minute quantity of lead. Attempts to give these rods suitable heat treatment to make them strongly magnetic were failures except in the case of the rods of composition $AlMnCu_2$. This material became suitably magnetic by simply quenching at 850° C., as recommended by Valentiner and Becker.* For placing the facilities of his metallurgical laboratory at our disposal for all this heat treatment, I am much indebted to my colleague, Prof. Donald Clark.

The rods of $AlMnCu_2$ were brittle, and not entirely free from holes, as X-ray examinations at Schenectady showed. In the attempt to grind the best of them into a true cylinder the rod broke into pieces. Several such pieces were then ground with flat ends in the Astrophysical Shop; and an unwound rotor, latest style, of approximately the standard short length, was constructed with great skill by Mr. Julius Pearson. Three lengths of material were cemented closely together with litharge and oil in closely fitting cylindrical brass sleeves. The rotor was hung up and tested for geometrical symmetry and was found to be exceedingly true.

In spite of this high degree of mechanical perfection, however, gyromagnetic observations showed a great deal of asymmetry in I and II. Three sets of observations were made, giving $\rho e/m = 0.96 \pm 0.12$. Further work was postponed until a change in method could be made, or until the storage battery plant of the laboratory, which was no longer in condition to drive the equipment satisfactorily, could be overhauled.

E. CONSIDERATION OF CERTAIN SOURCES OF ERROR IN THE WORK OF OTHERS

§ 55. DR. BATES' CLAIM THAT THE GYROMAGNETIC RATIO FOR FERROMAGNETIC SUBSTANCES IS EXACTLY *m/e*. In what precedes a large amount of conclusive evidence from measurements on the Einstein and de Haas effect has been presented which shows that the gyromagnetic ratios for many ferromagnetic substances very definitely exceed the value m/e. The extensive researches on the Barnett effect described in II had already yielded the same result, and will be discussed further below, where the conclusions from the two investigations will be compared.

In a brief article in Nature, however, Dr. L.

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* Zeit. f. Phys. **83:** 371–403, 1933. I am indebted to Professor Valentiner for further advice by letter.

F. Bates* contends that the true value of the gyromagnetic ratio for ferromagnetic substances (except pyrrhotite) is exactly m/e (which is the value, within the experimental error, derived from my first work on the magnetization of iron by rotation in 1914), and therefore that the larger values obtained in my laboratories since are not correct. He bases his claim on work done by Sucksmith and himself, by Coeterier and Scherrer,† and by Ray-Chaudhuri.‡

The investigation of Ray-Chaudhuri is an extensive and accurate piece of work on a number of iron oxides. In the preliminary paper, which Dr. Bates quotes, the gyromagnetic ratio was given as only slightly greater than m/e. But the final paper has since appeared, and in it the ratio is given as $1.03 \times m/e$ and $1.02 \times m/e$ for all of the oxides, in almost exact agreement with my value for iron.

The work of Coeterier and Scherrer on iron was incidental to their work on pyrrhotite, and was apparently restricted to a single determination for each of two very small specimens, with small magnetic moments approximately equal to those of their specimens of pyrrhotite. The values obtained were $m/e \times 0.995$ and $m/e \times 1.01$. But the authors do not claim precision, they give no estimate of the error, and the data presented are insufficient to enable the reader to form an adequate independent judgment of its magnitude.

The results of Sucksmith and Bates, reduced for the new value of e/m (viz. 1.757×10^7 e.m.u.) are summarized in Table 38. Group I contains the joint work of the two investigators; group II and III, additional work by Sucksmith.

Unquestionably these results furnish no certain evidence that $\rho e/m$ for any of the materials differs from unity. The value 1.05 for Cu-Ni alloy, however, which is quoted both by Sucksmith and by Bates as favorable to the 1.00 value for nickel, would certainly seem to support my value for nickel, which is 1.05, more than it supports the value unity.

Sucksmith and Bates believe that the total error in group I is no greater than 1 or 2 per cent. But the data published with respect to some of the constants and measurements are insufficient to enable the reader to form an adequate independent judgment of the magnitude of the possible error due to these; and there are other possible sources of error, which are discussed below.

§ 56. The Correction to the Constant of the Induction Solenoid. In making this correction Sucksmith and Bates adopted a procedure which is equivalent to assuming that a uniform solenoid wound *on the rotor, and of exactly the same length,* is equivalent to a much longer or infinite solenoid. When the diameter of the rotor is small in comparison with its length, as in their work, the assumption is approximately, but not exactly, justified. There is no merit in making the two lengths exactly equal. The exact theory is as follows:

If a coil of wire traversed by unit electric current produces throughout any region the magnetic intensity γ, then a body with magnetic moment μ inserted in this region with its axis parallel to the direction of γ sends through the coil the magnetic flux $\phi = \mu\gamma$. If the body is a short rod placed axially in a much longer solenoid, $\gamma = 4\pi n$, where n is the number of turns per unit length.

If the rod is placed in a shorter solenoid, with the same pitch, the flux is $\varphi' = \mu\gamma_0$, where γ_0

TABLE 38

Gyromagnetic Ratios from the Work of Sucksmith and Bates

Group	Material	No. Sets	$\rho e/m$	Range of $\rho e/m$	Approx. 2 × vibration amplitude in m.m.
I	Iron	16	0.998 ± 0.012	0.966–1.020	10–20
	Nickel	6	0.994 ± 0.004	0.980–1.002	5–10
	Heusler Alloy	14	0.994 ± 0.006	0.980–1.006	5– 8
II	Cobalt	9	1.022 ± 0.064	0.908–1.152	1
	Magnetite	10	0.982 ± 0.048	0.886–1.138	0.7
III	Ni-Cu Alloy (56% Ni)	6	1.05 ± 0.10	0.95–1.18	$\leqslant 10$

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* L. F. Bates, Nature **134:** 50, 1934.

† See F. Coeterier, Helv. Phys. Acta **8:** 522, 1935.

‡ D. P. Ray-Chaudhuri, Ind. J. of Phys. **9:** 383–414, 1935.

(less than $\gamma = 4\pi n$) is the *effective* constant of the coil for the particular rod in its definite position.

In the work of Sucksmith and Bates, and in most of my own, the gyromagnetic ratio ρ is determined in effect from the formula $\rho = A\gamma_0$, A including all the factors involved other than the constant of the solenoid. But in the work of Sucksmith and Bates γ_0/γ was determined by the procedure referred to above, which should give *too large* a value of γ_0, and thus of ρ.

Although the correction of any error due to this precedure would make the discrepancy between my values and those of Sucksmith and Bates larger instead of smaller, I have thought it desirable to make independent determinations of γ_0/γ for nickel and iron rods similar to those used in their work and in fields similar to theirs. I have therefore made such determinations, with a uniformly wound solenoid of length 53 cm. and of the same diameter (1.00 cm.) as that of their induction solenoid and provided with central taps distant apart the exact length of their rotors, viz. 15.2 cm.

Each of three rods of annealed nickel of this length, and with diameters 1.57 mm., 2.08 mm., and 2.30 mm., and each of three rods of Armco iron of the same length and with diameters 1.58 mm., 2.38 mm., and 3.2 mm. was in turn placed centrally and coaxially within this solenoid, and the whole mounted centrally and coaxially within a much larger magnetizing coil (A) of about the dimensions of that of Sucksmith and Bates, and traversed by a current which produced a field very nearly uniform in the region occupied by the rod and of the same strength (90 gausses) as that used by them. By several careful series of ballistic measurements the ratio γ_0/γ was determined for each of the rods.

The magnetizing coil A was made of 7 shorter cylindrical coils, all exactly alike, placed end to end on a long bakelite tube.

To vary the conditions of the tests, another set of determinations of γ_0/γ was made with the coil A lengthened by adding another of the short coils at one end, without other change. The extended coil will be referred to as coil B.

The smallest two iron rods were tested with coil A, all three with coil B. For the first two the agreement was almost exact for A and B, and γ_0/γ was very nearly a linear function of the diameter, increasing from about 0.944 to about 0.956 as the diameter increased. The interpolated value for a diameter equal to that of Sucksmith and Bates' smaller iron rod is 0.9445; for the diameter of their larger rod, 0.9452. The differences for the two coils A and B were less than the experimental error.

With coil A, γ_0/γ for the three nickel rods was found to be 0.937 ± 0.003; with the longer coil B, 0.935 ± 0.007. No certain differences were manifest between the results for the different rods.

According to these experiments, Sucksmith and Bates' γ_0/γ for nickel is too small by the fraction $0.936 - 0.923 = 0.013$. Their value for the smaller iron rods (5 sets) is in almost exact agreement with mine, the difference being 0.944–0.942, a quantity less than the experimental error. For their larger iron rods (11 sets) their value is apparently too large, the difference being $0.962 - 0.945 = 0.017$.

According to this, Sucksmith and Bates' value of ρ for nickel should be increased by 1.3 per cent; while their value for the larger iron rods should be decreased by 1.7 per cent, and thus their final mean for iron by 11/16 of this, or about 1.2 per cent. With these alterations, and the change in the value of e/m, their results for iron and nickel, respectively, would become 0.986 m/e and 1.007 m/e.

Thus such error as occurred in making the end corrections cannot explain the discrepancies between their work and that of Ray-Chaudhuri, Barnett and Barnett, and myself.*

§ 57. OTHER CORRECTIONS AND POSSIBLE CAUSES OF DISCREPANCIES BETWEEN RESULTS. In the same article Dr. Bates indicates that he believes I have overestimated the importance of eliminating the effects of electron inertia, as well as the effects of a residual vertical magnetic field and of magnetostriction. Electron inertia effects are negligible in all work on this subject except that part of my own in which the magnetizing current traverses a coil wound on the rotor; but I have suspected the other effects, in association with asymmetry and half-cycle inequalities, responsible for appreciable errors in much of the work done on rotation by magnetization.

The correction for electron inertia in my experiments (appreciable only when the magnetizing coil is wound on the rotor) has ranged from 0.1 per cent for certain iron and permalloy rotors in a 2-gauss field to more than 7 per cent for a rotor of pure cobalt. While negligible, or nearly negligible, in some cases, it is by no means so in all. Moreover, the theoretical value of the correction has been completely confirmed by direct experiments on copper (See IV). The approximate fractional value of the correction is $2\mu'/\mu$ where μ' is the magnetic moment of the magnetizing coil and μ that of the magnetic material.

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* Since this was written, moreover, Kikoin and Goobar in a preliminary paper have published for iron at a liquid air temperature the value $\rho e/m = 1.026$. An estimate of the error is not given. See C. R. Acad. Sci. U.S.S.R. **19:** 249, 1938.

As to the vertical intensity, data are given in III and V, and additional data are given in this paper, to show that its elimination is sometimes necessary, even in the case of easily magnetizable materials like soft iron and permalloy. In many cases, where the degree of symmetry is high and the magnetizing field strong, it is doubtless immaterial whether the vertical intensity is annulled or not. But when it is not annulled evidence should be adduced to prove that it is without effect.

For evidence that the elimination of the vertical intensity is at least sometimes necessary even in the case of soft iron, see Table 14 and the graph in Fig. 8. For possible evidence in the case of permalloy see Table 6 (Group III).

Sucksmith in his work on nickel-copper alloys,[†] has made experiments which convince him that the vertical intensity is without effect. But the error in that work is so large (estimated by Sucksmith at 10% per cent) that the result cannot be considered generally applicable.

Dr. Bates' idea that it is only on account of possible magnetostrictive effects that I have considered it necessary to eliminate the vertical intensity of the earth's field is not correct. That part of the error which is connected with magnetostriction can be eliminated by reversing the connections to the power supply. But even when this is done, as in my own work, there is sometimes left a definite error, which can be eliminated only by destroying the vertical intensity. See III, pp. 285, 286, and VI, § 32 (c).

As to magnetostriction, I had suspected that a considerable part of the discrepancies between the work of Sucksmith and Bates and my own was due to the fact that they did not make systematic reversals of the connections between commutator (or generator) and the magnetizing coil in order to correct for asymmetry of the half-cycles of current and magnetization. In my own work great improvement immediately resulted from the adoption of this practice. Indeed, it has usually been more important to make this reversal (between switch positions I and II), than to work with two azimuths of the suspended system differing by 180°, as many of the preceding tables show.[‡]

§ 58. THE HALF-CYCLE ASYMMETRY REVERSAL AND THE AZIMUTHAL REVERSAL. The reversal I–II not only eliminates the effect of magnetostriction, whether the magnetizing coil is fixed to the coil or fixed to the earth, but in the latter case it also eliminates the effect of the axial torque (see III § 12 (b)) due to the action of the horizontal part of the intensity of the alternating field on the alternating horizontal moment ν of the rotor; but if the half-cycles of current and magnetization are equal, the fundamental frequency of this torque is twice that of the current, and so its effect is negligible. If the half-cycles are not equal, there is also, in general, a residual torque with the frequency of the current, as pointed out by de Haas. On the assumption that both the vertical moment μ and the horizontal moment ν of the rotor are in phase with the current, this torque is in quadrature with the gyromagnetic torque. But while the first assumption may be *nearly true* in the case of flat-topped waves, it is not *exactly* true; and the second may be far from true. This torque may thus have an in-phase component which is not negligible and may definitely require the I–II reversal.

When the magnetizing coil is wound on the rotor this torque vanishes, and the necessity of the reversal, which the tables clearly show, is probably due entirely, or almost entirely, to magnetostriction.

The reversal in azimuth, introduced by de Haas, was used by Sucksmith and Bates in order to eliminate the effect of the torque due to the action of the (fixed) magnetizing coil on the residual permanent horizontal magnetization of the rotor, and is very important. The same reversal, as de Haas states, eliminates the effect of the torque due to the action of the residual horizontal component of the earth's magnetic intensity on the horizontal component of the alternating magnetization of the rotor. This effect of the azimuthal reversal is not referred to by Sucksmith and Bates, but in the work described here at least it is of greater importance than the other. For the two effects of the reversal together are measured by the quantities E–W in my tables; and this quantity is in general of the same order of magnitude whether the rotor is driven by a coil attached to and moving with it (in which case the effect of the first torque vanishes), or whether it is driven by a coil fixed to the earth, as in all of the work of most others.

[†] Nature **134:** 936, 1936 and Helv. Phys. Acta **8:** 205, 1935.

[‡] Sucksmith, in the articles just referred to, states that in the work of Sucksmith and Bates no effect of magnetostriction was ever witnessed. This is doubtless due in part to the fact that they did not make the reversal I–II. Throughout my own much more extensive work, even with suspended systems apparently much more symmetrical than theirs, there is abundant evidence, of several kinds, of the effect. It is even true that rotors, both in the moving coil arrangement and in the fixed coil arrangement, can be driven, usually with large amplitudes, by applying electromotive forces with just one-half their natural frequencies. In the case of the moving coil arrangement this is entirely due to magnetostriction. As pointed out earlier, error due to this effect, like most of the others, must vanish with complete symmetry about the vertical, which never exists.

The tables in this article give many illustrations of the quantities E–W and I–II in my work, for both superior and inferior rotors. The I–II values are in general greater, and often much greater, than the E–W values, a fact which justifies the statement made above with regard to the relative importance of the two kinds of reversal.

From the data given by Sucksmith and Bates for iron, nickel, cobalt, magnetite, and Heusler alloy, I have made approximate calculations of the quantities corresponding in their work to my |E–W|. They are given in Table 39.

TABLE 39

|E–W| in the Work of Sucksmith and Bates

	Minimum	Maximum	Mean
Iron	0.04	0.53	0.17
Nickel	0.07	0.45	0.28
Cobalt	0.7	6.0	1.9
Magnetite	0.65	2.4	1.6
Heusler alloy	0.27	0.74	0.45

A comparison of this table with my own tables will show that its values of E–W are in general much greater than my own. Since E–W and I–II both depend, though not in exactly the same way, on rotor asymmetry, and since my I–II values are, in general, greater than my E–W values, it would seem that the reversal corresponding to my change between I and II, would have been even more important in the work of Sucksmith and Bates.

The commutators used in my own work were all carefully made by a skillful machinist. Nevertheless the segments are not exactly equal. Thus in the single commutator with 1/8 inch gaps there is a mean difference between the lengths of the segments for the two half cycles of about 1 part in 170; in the similar commutator with ¾ inch gaps, the difference is about 1 part in 700; and in the triple commutator with 1/32 inch gaps, the difference is about 1 part in 1000.

As would be suspected, some of the trouble appears to come from the state of the brushes and the commutator surfaces or slip rings. In nearly all of the work described here a great deal of pains has been taken to keep these in good condition—in the case of the commutator surfaces, by accurate turning on the lathe, by treatment with fine sandpaper, and by cleaning with benzine or gasoline. There appears to be evidence that if the commutator surfaces are treated with fine sandpaper before *every set* of observations the asymmetrical effects are sometimes reduced. For a long time this has been our regular practice. Examination of our wave-shapes, both flat-topped and sine, with the oscillograph has shown only perfectly smooth and regular operation, at both low and high frequencies, and whether condensers and resistances were placed across the gaps or not. The oscillograph used, however, was not a sensitive one.

It is possible that in the work of Sucksmith and Bates the degree of half-cycle inequality in their electromotive forces, and the state of their contact surfaces, were such as to make the asymmetric effects less than in the work described here. The error, however, arises from these causes, coupled with the asymmetry of the rotor and the magnetizing field about the vertical; and this, to judge from the E–W values of Sucksmith and Bates, was, in general, much greater in their work than in that described here.

In the long run, with random mounting, $\overline{\text{E–W}}$ and $\overline{\text{I–II}}$ both tend to vanish; but in the work described here the results would be far less trustworthy if error were not eliminated by the practice of making *both* reversals.

§ 59. THE MINIMUM AMPLITUDE TEST FOR NEUTRALIZATION OF THE EARTH'S HORIZONTAL INTENSITY. In the work of Sucksmith and Bates, as well as in that of some others, the currents in the coils which are provided to neutralize the earth's horizontal intensity are varied until the resonance amplitude of the rotor is a minimum, when it is assumed that the residual horizontal intensity vanishes.

This would be true if, as further assumed, and only if, the torque* due to the earth's field were strictly in quadrature with the gyromagnetic torque, and were the only quadrature torque present. In general this is by no means true, as was in effect pointed out by de Haas, and as the E–W values for rotors driven by the coil wound rigidly on them prove. There are in general various quadrature torques present, and the minimum amplitude means only that their sum is a minimum for a certain residual horizontal intensity, which may be either small or great.

If this residual intensity remains constant, the major part of its effect is in general eliminated by observing with the suspended system in two azimuths 180° apart. But if the currents are adjusted to minimum amplitude for *each* azimuth of the system, the residual intensities are different for the two settings, and the torque due to the earth's residual field cannot be eliminated this way. It is not clear which procedure was followed in the work of Sucksmith and Bates.

It is clear from what precedes that when the field compensators are set in the way indicated the minimum amplitude observed for the apparent gyromagnetic torque may be either greater or less than that due to the gyromagnetic torque alone.

As an example from tests made here long ago, a difficult rotor known as Cobalt II (W. E. Cu Co.) gave a large residual amplitude A_0 for NPE when

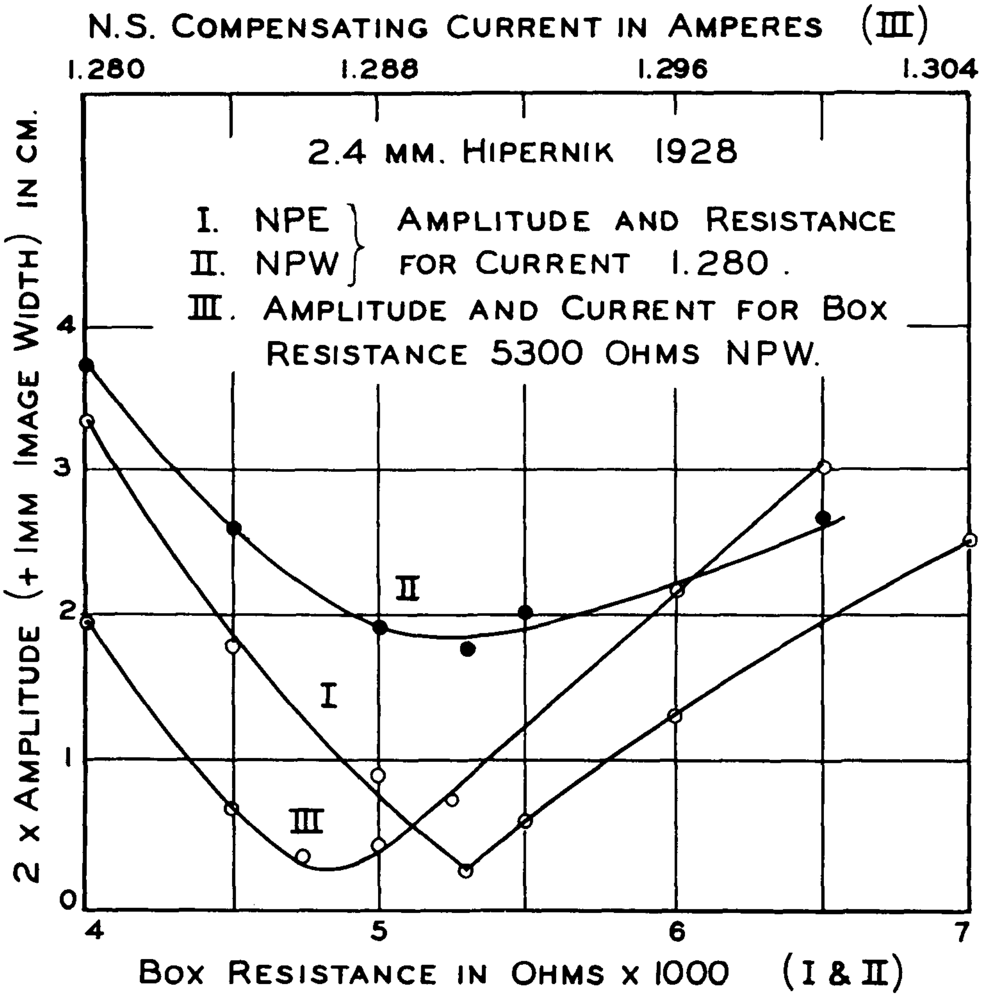

FIGURE 11.

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* This torque is proportional to the rotor's horizontal moment ν, which may not be in phase with the vertical moment μ. Thus it may not be in quadrature with the gyromagnetic torque, which is proportional to $\dot{\mu}$. Sucksmith and Bates think of the torque as a pure quadrature torque.

the currents X and Y in the N-S and E-W coils were given the proper values to compensate the earth's horizontal intensity. The proper value of X was 1.263 ampere. When X was changed to 1.276 ampere, $2A_0$ was reduced to about 1 cm. (the apparent gyromagnetic amplitude being about 7 cm.). For NPW, however, this value of X gave for $2A_0$ about 10 cm. This was reduced to about 1 cm. by changing X to 1.252 ampere—about as much below the correct value as 1.276 was above it. The calculated value of $\rho e/m$, viz, about 1.05, could not be assumed correct. When compensation was properly made, larger values resulted, but A_0 was so large that little reliance could be placed upon them, and the rotor was discarded.

Fig. 11 supplies another example, from somewhat rough observations on a Hipernik rotor. With the compensating currents set at the proper values to neutralize the earth's magnetic intensity (X being 1.280) Curves I and II for NPE and NPW were obtained, the minimum amplitude for the second being far in excess of that for the first.* In order to produce as small a minimum for NPW as given with $X = 1.280$ for NPE, it was necessary to increase X by more than 0.006, as shown by Curve III.

PART III. FURTHER DISCUSSION OF THE WASHINGTON WORK ON THE BARNETT EFFECT

§ 60. QUANTITATIVE RESULTS AND DIFFICULTIES WITH MAGNETIZATION BY ROTATION. In the article by Dr. Bates already quoted he refers to my work on magnetization by rotation as having been successful since 1914, and says that the results agree with those obtained from the converse effect "as well as could be expected." But he says they will not be considered further, and he does not mention them again. Thus he gives no weight whatever to them in deriving what he considers a correct value of the gyromagnetic ratio.

In reply to an inquiry from me about this he wrote me as follows: "The reason that I did not treat your experiments on magnetization by rotation in more detail in my article in *Nature* was that I have always considered that the experimental difficulties were such that one could not reasonably expect from them more than a welcome confirmation of the order of magnitude of the ratio obtained by other methods."

Now there can be no doubt that these experiments are difficult. Before they were successful with me, *and since*, they have been tried, or planned and given up, by a number of investigators, including very eminent investigators, in England, France, and America; but they have published no results.

When Einstein and de Haas learned that this work had succeeded with me they referred to it as "incomparably more difficult than their own," and Einstein has since told me that "he never thought it could be done."

Nevertheless I believe that no one who will read the original account of even the earliest experiments, those of 1914 and 1915 by the method of electromagnetic induction, can fail to acknowledge the strictly quantitative character of the work. The results of the two (independent) early investigations agree within a few per cent with one another, and with all the best work on gyromagnetic effects which has been done since. The work which followed, by magnetometer methods, became far more extensive and precise; and if Dr. Bates had read (as I cannot believe he has read) the original accounts of it, I think it would be impossible for him to refrain from giving it great weight.

To obtain precise results elaborate precautions of many kinds were necessary. The precise rotation work was always done after midnight, the most important part between the hours of two and four in the morning. To facilitate the work the Capital Traction Company of Washington even stopped the operation of its Chevy Chase streetcars while the measurements were in progress. Nevertheless even in the daytime, with both the sun and the street cars in full operation, and in a few minutes, observations of a quantitative character could be obtained, as the next section shows.

§ 61. OBSERVATIONS MADE IN THE DAYTIME BY VISITORS TO THE WASHINGTON LABORATORY. To see this, it is only necessary to inspect Table 40, which gives all the results obtained, in each case in the daytime and in a few minutes, by visitors to the laboratory. The only observations given are the mean magnetometer deflections; but the visitors also measured the sensitivity, and one of the investigators or an assistant measured the speeds.

As would be expected, the errors are far

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* The ordinates as given include the width of the image, viz., 1 mm., so that the actual minima are 1 mm. less than their curves indicate.

TABLE 40

RESULTS OF ROUGH OBSERVATIONS ON MAGNETIZATION BY ROTATION MADE IN THE DAYTIME BY VISITORS TO THE LABORATORY

Observers	Date	Rotor	No. of Scale Readings	Mean Deflection on Reversal of Rotation	Specific Magnetic Intensity of Rotation (λ)	Gyromagnetic Ratio $\rho \times e/m$
					$\frac{\text{gauss}}{\text{rev. per sec.}}$	e.m.u.
J. C. Merriam and L. A. Bauer	June 23, 1921	Steel III	8	0.48±0.16 cm	-3.6×10^{-7}	1.01
H. A. Lorentz	Apr. 25, 1922	Armco iron	5	2.65±0.45	4.3	1.20
C. A. Kotterman*	Apr. 26, 1922	Armco iron	16	2.32±0.24	3.8	1.06
E. L. Nichols and E. Merritt	Apr. 26, 1922	Armco iron	8	2.37±0.14	3.9	1.09
H. Crew	June 16, 1922	Steel III	8	2.8±0.5	4.0	1.12
R. C. Tolman, S. Karrer, and E. W. Guernsey	Aug. 22, 1922	Cobalt II	10	3.6±0.3	4.6	1.29
Mrs. C. A. Kotterman	Oct. 1, 1922	Steel III	8	3.75±0.15	3.76	1.05
W. Duane, E. M. Terry, and W. E. Tisdale	Dec. 12, 1922	Permalloy	6	4.45±0.12	3.75	1.05
W. S. Adams and C. G. Abbot	Dec. 15, 1922	Permalloy	10	4.72±0.10	3.9	1.09
A. Sommerfeld and F. J. Bates	March 8, 1923	Permalloy	8	4.95±0.05	3.75	1.05
A. P. Wills and Mr. and Mrs. S. L. Quimby	Apr. 20, 1923	Steel III	10	4.3±0.1	3.96	1.11
P. S. Epstein	June 2, 1923	Steel III	8	1.57±0.11	3.6	1.01
N. Bohr and P. D. Foote	Nov. 25, 1923	Cobalt II	8	2.58±0.12	3.4	0.95

* Mr. Kotterman was our research assistant, but he had never before made the observations himself.

greater than when the elaborate precautions necessary for precise work could be taken; but the mean value of the gyromagnetic ratio differs by only three per cent from that of the precise work, and the mean error is only about six per cent.

The mean value of λ from all these observations is $-(3.87 \pm 0.22)\ 10^{-7}$ gauss per rev. per second, corresponding to $\rho = (1.08 \pm 0.06)\ m/e$. The mean value of λ from the precise (nocturnal) observations at the highest speed is -3.76×10^{-7} gauss per rev. per second, corresponding to $\rho = 1.05\ m/e$.

The mean values of $\rho e/m$ obtained for the four rotors in these observations are given in Table 41 together with the values obtained from the standard measurements made on the same rotors under the best conditions.

Table 40 is published not only because it shows what can be done under extremely adverse conditions, but also because a great deal of interest has been expressed in it by the many who have seen it.

§ 62. SLIGHT REVISION OF THE WASHINGTON RESULTS ON THE INTRINSIC MAGNETIC INTENSITY OF ROTATION $\lambda = 2\pi\rho$. The quantity $\rho\ (= \lambda/2\pi)$ derived from the observations in II is given by Equation (8), II, p. 170 on division by 2π. The equation for ρ may thus be written

$$\rho = A/Q$$

where Q is the ratio of *rotor sensitivity* to *magnetometer sensitivity*, and A contains the other observed quantities and constants. Of the adequate precision of the quantities involved in A there was never any doubt; but suspicion of transient defects in the insulation of one of the coils on which Q directly depends, aroused long after the main experiments were completed and the results calculated, made desirable certain additional measurements. The new tests consisted chiefly of (1) additional determinations of the quantity Q for Steel III (viz. Q_S), which will be denoted by Q_S', and (2) series of determinations for each of the other rotors of the ratio of Q to Q_S, which will be designated by R.

(1) It has been practicable to improve somewhat the calculations of the three values of Q_S' obtained by two independent methods and given in II § 23 (1), the new values being -0.8, 0.1 and -1.1 per cent greater than the value of Q_S for the same magnetometer. The mean is -0.6 ± 0.3 per cent greater, which would indicate (except for probable errors in magnetometer

TABLE 41

COMPARISON OF ROUGH AND STANDARD VALUES OF $\rho e/m$

Rotor	Steel III	Armco Iron	Cobalt II	Permalloy
No. sets	5	3	2	3
$\rho e/m$	1.06±0.04	1.12±0.06	1.14±0.017	1.06±0.02
$\rho e/m$ std.	1.05	1.03	1.07	1.06

settings, etc., for Q_S') that the values of λ and ρ for Steel III are *too small* by this amount.

(2) The check on the values of Q and ρ obtained in the main observations of II provided by the new measurements of R can be made more perspicuous by the arrangement of results given in Table 42 than by that of II, Table III, p. 168. The means of the values of R in II, Table III, are given in column 6. Column 5 gives the values Q_C of Q calculated for the different rotors from Q_S (for the two different magnetometer systems) and R by the formula $Q_C = RQ_S$. Column 4 gives the Washington values of Q (series B); column 7, the Washington values of ρ; and column 8, the values ρ_C of ρ calculated from the formula $\rho_C = \rho Q/Q_S$*; column 9, the quantities $\rho_C - \rho$. The calculation of ρ_C depends for its validity upon the assumption that the ratio of the moment of the upper and lower magnetometer systems remained sensibly unaltered throughout the series. In much of the earlier work we determined this ratio frequently and with considerable precision. But this became unnecessary in the later work on account of the more elaborate and more nearly exact procedure adopted for securing *effective* astaticism; and in the course of Series B we made only two rough measurements of the ratio for the 3-magnet system magnetometer, a few days apart, near the middle of the series. That the ratio of the moments remained constant, or approximately constant, is indicated by the fact that $\rho_C - \rho$ shows no systematic change with the time as the series proceeded.

The degree of agreement between columns 4 and 5 shows that in nearly every case no defect of insulation could be responsible for any consequential excess of the observed value of ρ above its true value.

An exception appears to occur in the case of the observations on Steel IV for September 30–October 2, for which Q is much smaller (3 per cent) than Q_C, ρ much greater (3 per cent) than ρ_C, while for the December observations the agreement is excellent. The value of Q for the earlier group of observations was obtained from two closely concordant determinations made on different days; nevertheless I am convinced that the leads of the calibrating coil must then have been in an exceptional position in which a slight short-circuit occurred during both tests.† The September–October value of Q has therefore been rejected, and the observations reduced with the value of Q obtained in December, which agrees well with Q_C, and brings ρ and ρ_C into good agreement.

While writing VI Table 23-1, I considered the evidence to indicate that the value of Q for the October observations on electrolytic iron was in error, as the earlier value for Steel IV seemed to be, and made a similar correction. The close and simultaneous agreement, however, between ρ and ρ_C and between Q and Q_C for this rotor shows that the correction was not justified. In spite of diligent searches, I have never succeeded in finding any explanation of the large value of ρ for this rotor. (See footnote p. 453.)

The values of ρ (and ρ_C) in the table differ slightly from those printed in VI Table 23-1, for three reasons. In the first place, the values of the end correction K obtained by a later and somewhat more direct process (see II § 22, footnote 30) have been applied in place of the earlier values. This increases the values of ρ (and ρ_C) by

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* This follows at once from the relation $\rho_c = A/Q_c$ and $\rho = A/Q$. The values of ρ_c given in VI § 23 were correctly calculated from the above formula; but the ratio A_s/A, which should multiply ρ in Equation 18-1, was omitted in the text. When this ratio is inserted the formula becomes equivalent to that just given.

† The evidence now seems to indicate that a partial short-circuit occurred on one occasion before the beginning of Series A and Series B, when a rather rough resistance measurement *appeared* to give too low a value. This was rejected as in some way incorrect because it was quickly followed by a perfectly conclusive insulation measurement which showed no defect whatever. It now seems quite probable that both measurements were correct, the leads being arranged in an exceptional manner in one case.

TABLE 42

SLIGHTLY REVISED VALUES OF $\rho e/m$ FROM WASHINGTON INVESTIGATION ($e/m = 1.757 \times 10^7$ e.m.u.)

1 Rotor	2 Date	3 No. Sets	4 Q	5 Q_c	6 R	7 $\rho e/m$	8 $\rho_c e/m$	9 $(\rho_c - \rho)e/m$
Electrolytic iron II	Oct. 20–21	4	2.337	2.350	0.991±0.012	1.108	1.102	−0.006
	Oct. 23–26	9	(2.337)	2.350	0.991±0.012	1.094	1.088	−0.006
	Dec. 8	5	2.379	2.350	0.991±0.012	1.069	1.082	+0.013
	Means	18				1.091	1.090	
Armco iron	Oct. 14	10	1.684	1.691	0.713±0.002	1.027	1.023	−0.004
Norway iron	Dec. 29–30	6	1.885	1.849	0.780±0.005	1.032	1.052	+0.020
Steel I	Dec. 25–27	9	1.802	1.811	0.764±0.002	1.047	1.042	−0.005
Steel III	Sept. 10–12	6	2.355		1.000	1.044		
	Oct. 3–4	5	2.371		1.000	1.051		
	Dec. 3–Jan. 1	4	2.371		1.000	1.037		
	Means	15				1.044		
Steel IV	*Sept. 30–Oct. 2	8	(2.026)*	2.037	0.859±0.003	1.073	1.067	−0.006
	Dec. 22–24	13	2.026	2.037	0.859±0.003	1.043	1.038	−0.005
	Means	21				1.054	1.049	
Nickel I	Nov. 8–10	9	1.752	1.802	0.760±0.002	1.049	1.020	−0.029
Nickel III	Nov. 2–3	4	2.199	2.224	0.938±0.002	1.025	1.014	−0.011
	Nov. 4–5	6	(2.199)	2.224	0.938±0.002	1.006	0.994	−0.012
	Means	10				1.014	1.002	
Cobalt II	Nov. 19–21	6	1.937	1.878	0.792±0.004	1.077	1.111	+0.034
	Nov. 22–27	7	1.943	1.878	0.792±0.004	1.066	1.103	+0.037
	Means	13				1.071	1.107	
Heusler alloy I	Dec. 9–12	10	1.145	1.124	0.474±0.001	1.012	1.031	+0.019
Permalloy	Aug. 31–Sept. 1	4	2.960	2.946	1.251±0.005	1.049	1.054	+0.005
	Sept. 2–6	7	1.386AF		(1.255 AF)	1.074		
	Dec. 13–14	5	2.936	2.966	(1.251±0.005)	1.034	1.023	−0.011
	Means	16				1.055†	1.037‡	
Nickel-iron	Nov. 16–18	10	1.047	1.046	0.441±0.002	1.017	1.018	+0.001
Cobalt-iron	Dec. 16–18	6	2.585	2.610	1.101±0.004	1.068	1.057	−0.011
Cobalt-nickel	Oct. 5–6	4	1.651	1.641	0.692±0.002	1.069	1.076	+0.007

* The uncorrected values of Q and $\rho e/m$ are, respectively, $Q = 1.973$ and $\rho e/m = 1.102$.

† For all 16 sets. ‡ For the 9 sets with equatorial position of rotor.

amounts varying from 0.0 per cent to 0.3 per cent—negligible or almost negligible quantities when the other errors are considered. In the second place, the values of ρ and ρ_C are given separately for all the groups of II Table XIII; while, for brevity, only mean values were given in VI. In the third place, the small corrections discussed below in § 63, and due to the motion in azimuth of the lower magnetometer magnet, have been applied.

§ 63. Correction Due to the Motion in Azimuth of the Magnetometer System. In II § 40 the possible error due to the change of magnetization of the rotor arising from the motion in azimuth of the lower magnetometer magnet is considered. For the magnetometer with the six-magnet systems in the principal position LEQ the change in the axial intensity *at the center of the rotor* produced in this way, is, for the Cobalt-Iron rotor, about 1½ per cent* of that produced by reversing the rotation. The *mean* axial intensity along the length of the rotor produced in this way is of course much smaller, but its effect is impossible to compute. No error arises from this source if the calibrations are made with intensities equal to the intrinsic intensity of rotation. But in most of the calibrations the intensity was some sixty times as great as the maximum intensity of rotation. Thus, while the effect practically vanishes in these calibrations, it may remain in the rotation experiments.

On this account, although the maximum possible effect is small, it has seemed desirable to make an experimental determination of the actual error involved, as follows.

To determine the correction for the magnetometer position LEQ a standard solenoid *C*, with dimensions nearly the same as those of the short standard used in the Washington experiments, was placed with its axis horizontal, as in Fig. 12. Two small short coils *A* and *B* wound on the same bobbin, and nearly alike, were mounted with their axes horizontal and 12.9 cm. from the axis of *C* and opposite its center. *A* was connected in series with another coil *A′* and, through a reversing switch, with a battery and rheostat. *A* could be replaced at will with the coil *C*. *B* was connected in series with another coil *B′*, and with a ballistic galvanometer and rheostat. By moving *A′* relatively to *B′* the mutual inductance of *AA′* and *BB′* was made nearly to vanish, as is usual with induction balances.

Then a current 0.06 ampere was repeatedly reversed through coils *AA′* (1) when the cobalt-iron rotor was mounted symmetrically in coil *C* and (2) when it was removed to a distance. The mean throw in the first case was 0.467 cm.; that in the second, 0.365 cm., difference 0.102 cm. The area of the coil *A* was 13.8×10^3 cm², so that its magnetic moment was $13.8 \times 10^3 \times 6.0 \times 10^{-3} = 83$ e.m.u. Thus the change in the magneti-

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* Instead of 3 per cent, given in II, through the omission of a factor 2.

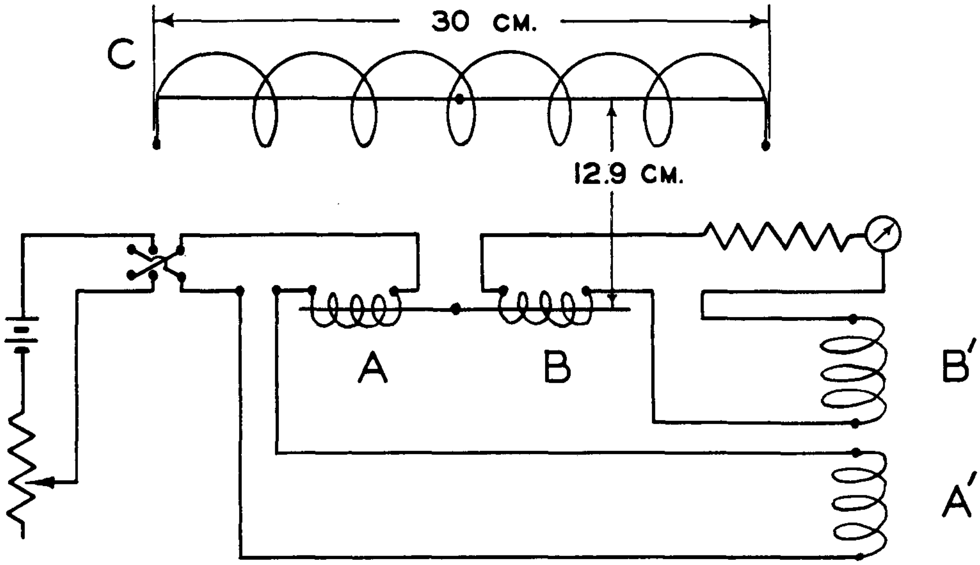

Figure 12. Method of obtaining correction for azimuthal motion of magnetometer system.

zation of the cobalt-iron rotor due to the reversal of the moment 83 e.m.u. of coil A with its axis 12.9 cm. from that of the rotor produced a deflection of 0.102 cm. through induction with A', similarly situated with A as regards the rotor.

The moment of a 6-magnet system of the magnetometer used in the Washington experiments was about 0.4 e.m.u.; and the magnet, normally at right angles to the axis of the rotor and with 12.9 cm. between their centers, was turned through an angle of about 0.0031 radian when the rotation of the cobalt-iron rotor at 61 r.p.s. was reversed. Thus if this magnet were to replace coil A in the above arrangement and to be turned through the angle mentioned, it would produce by induction with A', a deflection $(0.2 \times 3.1 \times 10^{-3})/83 \cdot 0.102$ cm. $= 7.6 \times 10^{-7}$ cm.

Coils A and A' were now replaced by coil C, and the mean throw was obtained for a number of reversals of a current 0.006 ampere in C. The mean throw was about 0.71 cm. Had the coil C been very long, the intensity it impressed on the rotor would have been, in gauss/ampere, 21.7 (its constant if infinitely long) $\times$ 0.006 = 0.13 gauss, and the deflection due to the *change of magnetization of the rotor alone* would have been 0.71 $\times$ (1–0.006) cm., the quantity 0.006 here being the correction factor K for the Cobalt-Iron rotor (see II pp. 155–165). Thus the reversal of an intensity 0.13 gauss acting on the rotor would produce a throw of about 0.7 cm.

The intrinsic magnetic intensity of rotation at 61 r.p.s., is about 23×10^{-6} gauss. The reversal of this intensity in the last described arrangement would produce a throw $(23 \times 10^{-6}/0.13) \times 0.7 = 124 \times 10^{-6}$ cm.

Thus in the actual rotation experiment with the Cobalt-Iron rotor, the effect of the motion of the 6-magnet magnetometer magnet would be to make the observed effect too large by the fraction $7.6 \times 10^{-7}/124 \times 10^{-6} = 6.1 \times 10^{-3}$ or about 1 part in 160.

The fraction is nearly proportional to the specific moment of the rotor (II § 14, Table I) and to the absolute or magnetometer sensitivity A (II, Table XIII, column 28), as well as to the moment of the magnetometer magnet. It is thus one half as great for the 3-magnet system as for the 6-magnet system. The fraction ranges from about 0.1 per cent for the Heusler alloy and Hopkinson alloy rotors used with the 3-magnet systems to about 0.7 per cent for the Permalloy rotor when used with the 6-magnet systems.

Experiments similar to those just described, but with the Permalloy rotor, and with the small test coils placed with reference to it in the position designated in II as AF (about 17 + 15 cm. from the center of the rotor and on its axis produced), showed that in this arrangement the correction was inappreciable.

Part IV.

COMPARISON OF RESULTS OBTAINED BY THE TWO GYROMAGNETIC EFFECTS

§ 64. The Washington and California Results: Summary and Comparison. In Table 43 are collected the mean values of $\rho e/m$ obtained in this investigation by means of the Einstein and de Haas effect, and also the mean values obtained by means of the Barnett effect in the Washington observations, taken from Table 42. The discrepancies are all small except in the case of Yensen's Electrolytic iron and Cobalt-Iron. For these discrepancies of several per cent, no explanation has been found.*

The mean values of $\rho e/m$ obtained from the two investigations for materials studied in both are in close agreement, 1.053 from the Barnett effect, and 1.047 from the Einstein and de Haas effect.

The values of $\rho e/m$ in Table 42 are from the best observations in II, viz., the 159 sets at the highest speed (ca. 61 r.p.s.) in series B of that paper. The mean for all the 14 rotors is 1.046. The means for all the four speeds used agreed well, as shown in II and VI. The next best group in the series is that for the next lower speed, ca. 31 r.p.s., which gave as the mean, from 163 sets, 1.055. Moreover, the preceding series, Series A, gave for the higher speed, from 150 sets, the value 1.054; and for the lower speed, from 100 sets, the value 1.060. The degree of agreement between these results and the mean for the new investigation on the converse effect much more than justifies the authors of II in their claim of an error for their mean not greater than 2 per cent. Indeed it now appears that for *no one of the materials* used in II, with the exception of Electrolytic iron and Cobalt-Iron, is the mean value of ρ from II in error by more than this amount; and the error is usually much less. The values of ρ for Permalloy and Iron, as determined

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* Measurements made in a new investigation on magnetization by rotation since this was written do not confirm the high Washington values for these substances, while they do give high values for Cobalt and Cobalt-Nickel. The work is not yet completed.

TABLE 43

$\rho e/m$ from Barnett Effect and Einstein and de Haas Effect

Material	Barnett	E. & de H.	Material	Barnett	E. & deH.
Armco iron	1.027	1.032	Hopkinson's Iron-Nickel alloy	1.017	1.024
Norway iron	1.032	——	Permalloy	1.055	1.047
Honda iron	——	1.023	Cobalt	1.071	1.090
Yensen iron (electrolytic)	1.091	1.034	Cu-Cobalt	——	1.082
Cold-rolled steel	1.048	1.039	Cobalt-Iron	1.068	1.027
Nickel	1.032	1.052	Cobalt-Nickel	1.069	1.077
Hipernik	——	1.052	Heusler alloy	1.012	——*

Mean $\rho e/m$ from Barnett Effect = 1.053 for materials studied in *both* investigations.
Mean $\rho e/m$ from Einstein and de Haas Effect = 1.047 for materials studied in *both* investigations.

* The value given in § 54 is not inserted here because of its preliminary character.

TABLE 44

Historical Tabulation of $\rho e/m$ for Ferromagnetic Substances

Date	Investigators	Effect Investigated	Material	$\rho e/m$	Sign of Charge in Ampèrian Whirl
1914	Barnett	Barnett	Steel	1.01	negative
1915	Barnett	Barnett	Steel	0.95	negative
1915	Einstein & de Haas	E. & de H.	Iron	2.0	indeterminate
1916	Einstein & de Haas	E. & de H.	Iron	—	negative
1917	Barnett	Barnett	Iron, Nickel, & Cobalt	$>1<2$	negative
1918	J. Q. Stewart	E. & de H.	Iron	1.02	negative
			Nickel	0.94	negative
1919	E. Beck	E. & de H.	Iron	1.06	negative
			Nickel	1.14	negative
1919	G. Arvidsson	E. & de H.	Iron	0.94	——
1922	H. Claassen*	E. & de H.	Soft iron to Glass-hard steel	1.13 to 2.4	——
1923	Chattock & Bates	E. & de H.	Iron	1.01	negative
			Nickel	1.01	negative
1920–25	Barnett & Barnett	Barnett	Numerous†	1.01 to 1.09	negative
1923	Sucksmith & Bates	E. & de H.	Fe, Ni, Heusler alloy‡	0.99+ to 1.00−	negative
1925	Sucksmith	E. & de H.	Cobalt‡	1.02	negative
			Magnetite	0.98	negative
1934	Sucksmith	E. & de H.	Cu-Ni alloy‡	1.05	——
1933–35	Coeterier & Scherrer	E. & de H.	Iron	1.00+	negative
			Pryrhotite	3.2	negative
1935	Raychaudhuri	E. & de H.	Iron Oxides	1.03 & 1.02	——
1931–38	Barnett	E. & de H.	Numerous¶	1.02 to 1.09	negative
1938	Kikoin & Goobar	E. & de H.	Iron**	1.03–	——

* See abstract of Hamburg dissertation in Phys. Ber. **4**: p. 359, 1923. I am indebted to Prof. R. Becker for this reference.

† See Tables 42 and 43.

‡ See Table 38.

¶ See Table 43 and the numerous earlier tables in this work.

§ As pointed out by H. A. Lorentz. See A. Einstein, Verh. d. D. Phys. Ges. **18**: 173, 1916.

** See § 56, above, at the end.

from the present investigation, are probably correct to one-half per cent; while it is unlikely that the mean value of ρ given in Table 43 from this investigation for any of the other materials is in error by much more than one per cent.

§ 65. SUMMARY OF ALL RESULTS HITHERTO OBTAINED ON GYROMAGNETIC RATIOS FOR FERROMAGNETIC SUBSTANCES. References to gyromagnetic effects in the literature of physics of the last twenty years and more, including even very recent literature, contain so many errors as to the magnitudes of the effects and the history of their discovery and measurement that it seems important, in concluding this paper, to present the adjoining historical table (Table 44) in which the chief results of all the investigations are given, and in chronological order.

§ 66. ACKNOWLEDGMENTS. In the course of this work a great deal of help has been received from many individuals and organizations, and it is a pleasure to express here my gratitude to them all. Some of them are mentioned in the preceding text. Special mention should be made of those who have acted, *seriatim*, as laboratory assistants since the completion of V, viz. Mr. B. W. Sorge, Mr. K. K. Illingsworth, Mr. L. L. Young and especially Dr. S. J. Broadwell. The work has been long continued and expensive, and could not have been accomplished without the joint support of the Board of Research of the University of California, the Norman Bridge Laboratory of the California Institute, in which the experimental work has been done, and the Carnegie Institution of Washington, to which I continue indebted for the use of most of the fixed equipment.

THE UNIVERSITY OF CALIFORNIA, LOS ANGELES, AND
THE CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA.

WHAT IS SOCIAL PROGRESS?

By L. J. Henderson

The Word

In this place, addressing the Academy on this occasion, I feel constrained to take—or to try to take—a position that shall be logical and scientific. I feel thus constrained even though, or better because, the question "What is 'social progress'?" seems to me logically a meaningless question about things that admit of little precise analysis.

The question is meaningless because there are no procedures, either measurements or mere observations, that can be regarded as suitable for its investigation. The question is also meaningless because the term 'social progress' is useless and worse than useless as a symbol in performing logical operations. The first of these assertions hardly requires further proof. Let us examine the second.

Oliver Wendell Holmes the younger, writing in his old age to a Chinese friend, once remarked:[1] "I have said to my brethren many times that I hate justice, which means that I know if a man begins to talk about that, for one reason or another he is shirking thinking in legal terms." I shall presume to make a single exegetical remark on Holmes's text: the phrase 'shirking thinking in legal terms' may be generalized to read 'shirking thinking in terms that can be used for even rough and ready logical purposes or for any sort of clear thinking.' Holmes's remark is not new, but it is the opinion—the induction—of a man who through a long life had formed his opinions from experience under the burden of responsibility. The same opinion was earlier expressed by Montaigne, who remarked:[2] "We say, indeed, Power, Truth, Justice: they are words that denote something great, but that something we are quite unable to see and conceive." A general treatment of the matter, not modern or rigorous, but sufficient for many purposes, may be found in Bacon's theory of Idols.[3] Probably, in most ages, at least a few sensible men have always known what Montaigne, Bacon, and Holmes knew; that many words, for other uses indispensable, are useless for clear thinking.

Why are terms like justice and social progress useless for clear thinking? First I suppose because, unlike such a word as contract, they have no accepted, fairly clear meaning, and again because, unlike such a word as cathode, they can be given an arbitrary definition only at the cost of strong persistent emotional opposition. Consider, for instance, the probable attitude of many thousands of Nazis to a definition of 'justice' that should make discharging hostile university professors unjust. Now consider a definition of 'social progress' that should make this same action socially unprogressive. The effect must be, at least for many people, not logical thinking, but strife, because strong feelings associated with the word inhibit its logical use and demand its nonlogical use. I suggest that an arbitrary definition of 'social progress' that should make, or should not make, the National Labor Relations Act an instance of social progress would, if the point were raised, arouse similar, if less violent, strife in this room tonight.

Bury has said[4] that for Turgot the idea of progress "was an organizing conception, just as the idea of Providence was for St. Augustine and Bossuet an organizing conception, which gave history its unity and meaning." In plain English this means that for Turgot the facts of history were subordinate to and had to be forced into conformity with certain lofty sentiments and dogmatic beliefs. I suspect that Turgot's view is still the prevalent view.

In general, men feel that words like justice and progress must have a meaning, must correspond to some deep reality, but they agree in only one respect: each feels that this reality, this unknown thing, must fully accord with *his* sentiments. So discussion of the attributes of justice or progress is like discussion of the attributes of God. It is the business of metaphysicians; it is clearly not the business of scientists. Therefore, if we are to pursue our subject, we must altogether abandon social progress as a logical symbol, or as a concept, or as an abstract metaphysical reality, and look at facts. Perhaps we may more easily reconcile ourselves to this lowly occupation by reflecting that the question "What is progress?" has been much debated, but without result, and that there is hardly any social change that has not been called progress by somebody.

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[1] *Justice Oliver Wendell Holmes: His Book Notices and Uncollected Letters and Papers.* Edited by Harry C. Shriver, New York, 1936, p. 201.

[2] *The Essays of Montaigne,* translated by E. J. Trechmann, London, 1927, Book I, Chapter 23, pp. 103–120.

[3] *Novum Organum,* Book I, Aphorisms XXXVIII–LXVIII.

[4] J. B. Bury, *The Idea of Progress,* London, 1920, p. 158.

THE SENTIMENTS

For Montaigne, power, truth, and justice—though they lack clearness—'denote something great'; and I do not believe that here Montaigne was speaking ironically. At all events, the social importance of the sentiments behind these words and of the words themselves as expressions of these sentiments is inestimable. Human societies have existed in which science and logic played only a small part, but there have been few indeed in which these sentiments did not have a great part. And in our own societies the words justice and truth themselves—the words themselves—have for thousands of years served to reinforce the sentiments, to arouse them, and perhaps even to instill them where they were lacking. Such words are indeed indispensable. But 'progress' is a modern invention which only yesterday attained to the dignity of personification. Today Progress is the most youthful, though not the fairest, of the goddesses, pale and wan of face, but not for love. We fear for her. Perhaps it is that fear which has brought us together tonight.

I wonder whether the word progress—so unlike 'truth' and 'justice'—is a trustworthy vehicle for the deep and abiding sentiments of men, except only for hope, or others that may have been recently, and weakly, associated, and whether it is not much more a sterile intellectual construction, for the greater part a rationalization of the eighteenth century *philosophes* and their nineteenth century heirs, the good liberals, under the influence of economic, political, and social change and the increasing control and exploitation of the environment. I suspect, in short, that for most of us the word progress suggests something less great than the words truth and justice do, for I believe that it expresses sentiments which are on the whole less deep in the human heart, because they have had a place there far less long. They seem not to have been a need of our forefathers. Unhappily this question—the social importance of the affective states, of the sentiments and emotions, associated with the word progress and with belief in progress—seems unripe for solution. I can but raise the question, express my doubts, and pass on.

THE RATIONALIZATIONS

The social importance of the *belief* in progress is another question. Considering this belief apart from the accompanying sentiments and emotions, as an intellectual influence, we may hazard the guess that its importance is small. For two centuries the belief has, no doubt, occupied the attention of political and social philosophers and of many others, but it is hard to see that much has come of this intellectual manipulation of the idea that has greatly changed human societies. On the one hand, the belief is difficult of application, being in no sense a scientific induction; on the other hand, it is perhaps only a quasi-religious dogma.

SOCIAL CHANGES

So we come to the question of the nature of social change. Social change is a fact. Here, however ignorant we may be, we stand on firm ground. Yet we are indeed most ignorant, and how unprepared to cope with the little we know! For there is nobody who has that intimate, intuitive familiarity with the phenomena which is the beginning of wisdom; and perhaps there can be nobody. Change is long, life short. Again there is nobody who has extensive systematic knowledge of social changes, for no good sociological classification of changes exists, to say nothing of broad information thus classified. And still again we have only just begun to think in terms of a generalized social system according to the example of the natural sciences, and what we can do with this social system or any other theory is but little. So in searching for the facts we must feel our way.

The Greek theory of recurrent world cycles, like the legend of the Golden Age, need not detain us. But there was also among the Greeks a theory of political cycles which, whatever its origin, came to be partly founded on observation. Polybius was a sensible man, and for Polybius, at least, it was an induction from experience that any form of government in due course takes on characteristics that lead to its destruction.[5] So another form arises, with a like result, and so after a time the first form returns. We may cautiously note this opinion, even though it seems likely that Polybius went beyond his facts, for many things that have lately been seen resemble the phenomena noted by Polybius and are consistent with his conclusions. Furthermore, old surviving constitutions are scarce today, and they seem to have been scarce also in times past.

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[5] *Histories*, VI; 3, 1; 9, 14.

From Vico to Spengler moderns have added their own to ancient speculations about historical cycles. Let us pass them by, for they seem to offer little that we can use. But meanwhile experience has been accumulating and it has gradually become plain that most things undulate. The πάντα, ρεῖ of Heraclitus is sharpened for us by a half unconscious induction into πάντα ῾ρεῖ καὶ ἀναρρεῖ. Tastes, doctrines, schools and forms in the arts and letters rise and fall as they do, often more quickly nowadays, in dress and in personal adornment. So they do in philosophy and in political and social theory. Is not the history of the theory of our subject a fair instance of this? So too economic processes ebb and flow.

In this one instance some progress (note the intrusion of our word) has been made in getting on from vague statement in phrases like those of the last paragraph to measurement and mathematical analysis; and we have, such as it is, the description and the theory of the business cycle. Clearly the phenomena are at least undulatory, even more than they are cyclical. Clearly the frequencies and the amplitudes of the waves of the business cycle seem to follow no simple rules. Clearly these waves seem to be, in general, unrelated by any simple laws to other undulatory processes. If all this were not so, some people, who have not, would have grown rich.

For many economists and for most men of affairs and politicians the waves of the business cycle are long waves, but for the historian of, say, three thousand years, they are short. Now there exists no more familiar, no more trustworthy historical generalization than this: During two historical periods, very vaguely defined, that are commonly referred to as ancient and modern times, there has been much intense activity in many of the affairs of European men; during an intervening period, sometimes called the Dark Ages, *in these same affairs* little intense activity. So the large-scale or long-period wave phenomena seem to be highly correlated.

The question arises: Considering that we find waves of short period which may be regarded as slight disturbances of waves of long period, is there a wave of longest period? If not, is there a trend? These questions are meaningless. They are not even properly formulated as a first step in considering whether there is anything more to say about longer scale processes, for such waves are, like the conceptual schemes of the physicists, partly constructions of our own minds that go beyond the facts. There is perhaps nothing more to say except the obvious remark that long ago there seems to have been no human activity on the earth and that lately there has been what we regard as rather too much. However, most social processes seem to be more or less undulatory—or are so conceivable. And in many instances what we may take as the trends of these processes appear to be segments of undulatory processes of longer period.

What can be said of other general aspects of social change? Auguste Comte distinguished three stages—the theological, the metaphysical, and the positive—in the growth of human societies. It is perhaps psychologically significant, though logically irrelevant, to note that in the end Comte tried to found a new religion of his own invention, which seems inconsistent, and that he was a philosopher rather than an observer. Little survives of Comte's philosophy of social change. No doubt he was right in his belief that the social importance of science, both pure and applied, had on the whole increased. It seems to have increased enormously since his time.

Herbert Spencer conceived social change as a predominantly orthogenetical evolution from the simple to the complex. He held that the evolution is largely determined by what he supposed to be a law of the instability of the homogeneous. The meaninglessness of all this was long ago demonstrated by the physicist Tait in a forgotten controversy with Spencer. Perhaps a remark of Clerk Maxwell's on a postcard addressed to Tait will suggest the natural attitude of a man of science in these premises. Maxwell wrote:[6] "Have you (read) Willard Gibbs on Equilibrium of Heterogeneous Substances? . . . Refreshing after H. Spencer on the Instability of the Homogeneous." Of course many things in human societies have in many respects greatly increased in complexity, for example, in technological complexity and in organization. But there seem to be other things in which the movement has been, even over long periods, the reverse. This is held to be the case of the grammatical structure of language. Moreover, it seems that what may be called the rituals and routines of European societies have run a parallel course with grammar. Sir Henry Maine's views[7] on the replacement of status by contract bear on this point.

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[6] C. G. Knott, *Life and Scientific Work of P. G. Tait*, Cambridge, England, 1911, p. 284.

[7] *Ancient Law*, Chapter V.

ENDS AND MEANS

In what I have just said I have tried to select fair specimens of descriptions of social changes and to suggest their limited utility for our present purpose. We may now turn to opinions about what social changes are desirable. Nothing is more familiar than Jeremy Bentham's 'greatest happiness of the greatest number.' Of this Edgeworth once said:[8] ". . . is this more intelligible than 'greatest illumination with the greatest number of lamps'?" And Edgeworth was right, for two superlatives make the solution of the problem indeterminate, and the phrase is accordingly meaningless. Yet how much stronger is the emotional appeal of two superlatives! And who among us has ever noticed the obvious fallacy that Edgeworth noticed? And why has Edgeworth's remark been generally forgotten while Bentham's phrase is nowhere forgotten? Well, the reasons for all this are many, complex, and tolerably obscure. Let us talk about them.

To begin with, there is no logical or scientific test of desirability, except in relation to an end or purpose, and then desire is a poor word; we had better talk about utility. For instance, a boy may just want to go swimming. In that event the means to his end become problems that admit of something like logical or scientific study, and we may even safely speak of progress toward that *given* end. But unless the desire in question comes into conflict with other desires, experience shows that it is ordinarily a waste of breath to reason about going swimming. On the other hand, this boy may want to go swimming because another boy is going swimming, because he wants company. Then the question of other means to this end may arise and is, in principle, within the range of logical and scientific analysis. Let us accordingly speak of utility as relative to an end or purpose and in principle determinate. Let us also note that statements about the ultimate ends of society are expressions of wishes that are in general as meaningless as Bentham's 'greatest happiness of the greatest number.'

Utilities are heterogeneous. There are present utilities and future utilities; for instance, spending and saving. There are material utilities like food and psychological utilities like music or poetry or philosophy. And there are utilities of the individual and utilities of society. Being heterogeneous, utilities are likely to conflict. One of the commonest kinds of conflict is that between individual and social utilities. In such conflicts we hear of egotism and altruism, private interest and public welfare, the good of the service and self-seeking.

Such are our present difficulties. There is, however, one ultimate social end, survival, that seems to be different from the others, for unlike progress or justice it can be observed. The Roman Catholic church survives; Nineveh and Tyre do not. These facts can be verified on April 12, 1939. Moreover, survival, both of the individual and of society, is a widely accepted end in all societies. If, then, we define, *arbitrarily* define, the survival of a society as an end, it is possible to investigate what is vaguely called the survival value of certain things for that society. And then in this sense we may speak of their social utility. Of course, this task is difficult, not to say in general fruitless. For the social sciences are not yet very helpful in a dispassionate inquiry.

There is also, perhaps, some slight possibility of judging the total state of a society in relation to its survival. Thus in, say, 1910 there was a general feeling that the Austro-Hungarian empire had small powers of resistance, the British Empire great powers of resistance. As we vaguely say, the one empire seemed to lack, the other to have stability. Many historians were prepared to give reasons—not very sound scientific reasons, to be sure—in support of these opinions.

SCIENCE AND SOCIAL PROGRESS

One has lately grown accustomed to hearing from distinguished men of science assertions addressed to the general public that the effects of science, especially the effects upon society, are altogether good or progressive, or useful. I can see no grounds whatever for such an opinion. In the first place, referring to what I have already said, I assert that the question is meaningless. In the second place, I assert that if, by means of arbitrary definitions, the question were given meaning, the answer could be found at best only after years of research.

Let us consider two specific questions. At the moment one of the most conspicuous effects of science is the development of military aviation. According to what and to whose emotional judgments does this constitute social progress? According to what arbitrary definitions, and for whom, does this today or will this ten years hence make for the stability of what societies? Surely the only possible answer is, we do not know; or rather this correct answer is an impossible answer for nearly everybody, because the passions, and fear above all, intervene.

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[8] *Mathematical Psychics*, London, 1881, p. 117.

Now consider population. There are grounds for thinking that the present state of most human societies is unstable, that this instability is largely associated with the growth of population, that this growth of population is largely due to applications of science and to a decline in the rate of infant mortality and that this decline also is largely a result of applications of science. Of course, we do not know all this. But in the face of such considerations and in view of our obvious ignorance, who shall say that the applications of medical science *may* not some day play a large part in bringing about the destruction of many societies? Again I say, we do not know. And I suggest that men of science may well consider the question whether they wish to assert what nobody can know. In this way they might at least avoid the risk of making such statements as the following: "It is science and its applications that . . have knit the whole world together into a unity that makes war an anachronism."[9]

One thing seems clear; among the innumerable effects of science on society, some must be harmful according to any definition, now or hereafter, to many individuals and to some societies.

It is also worthy of note that sometimes the effects of science upon society may well be only implicit functions of the state of science, but explicit functions of the *rate* of scientific development. In other words, the same scientific development proceeding rapidly might have one effect, proceeding slowly another quite different effect. It is a curious theorem that, regardless of such differences, the effects are desirable—or undesirable. But, however strange theorems of this type may be, dogmas of this type are very familiar.

Let us look again at the problem of stability. In the beginning of Morley's essay *On Compromise* you may read[10] (as many Victorians did with satisfaction and approval): "The right of thinking freely and acting independently, of using our minds without excessive awe of authority, and shaping our lives without unquestioning obedience to custom, is now a finally accepted principle in some sense or other with every school of thought that has the smallest chance of commanding the future." To such nonsense a simple faith in progress may bring a man like Morley. I hope that his false prophecy needs no further remark, but the phrase 'obedience to custom,' which is perhaps the worst nonsense of all,[11] must now be examined, for it may lead us to one final and positive conclusion.

Morley was in many ways a thoroughly typical Englishman of his period. His behavior was faithful, conscientious, decorous, decent, seemly, congruous with all standards of good breeding, suitable to his orderly occasions, becoming in a high-minded citizen, befitting a man of his standing and integrity. He was kindly, honorable, upright, fair-minded, just, truthful, law-abiding, scrupulous, and trustworthy. His unblemished conduct and equitable demeanor unfailingly and with regularity observed the proprieties in all things. Was this *obedience* to custom? Certainly not. And it was neither unquestioning nor questioning obedience. It was something like the *li* of Confucius,[12] the manifestation, in general unconscious, of a need as strong as the need for food, or stronger. Had he learned this behavior intellectually? Again, certainly not; neither he nor any other man. And such behavior did not even occur to him when he wrote of 'unquestioning obedience to custom.' But it was deeper than intellectual processes in his nervous system, for it was largely constituted (in the widest sense of Pavlov's school) of conditioned reflexes. If it had been interfered with, an experimental neurosis might have resulted.

Machiavelli once said[13] that the ancient religion "was one of the chief causes of the prosperity of Rome; for this religion gave rise to well-regulated conduct, and such conduct brings good fortune, and from good fortune results the happy success of undertakings." This was also the opinion of Polybius,[14] who had observed the Romans. Again the conditioned reflex, together with ritual and routine, predominates, for the Roman religion was an all pervasive cult, and it was little more. Polybius speaks of it as maintaining the cohesion of the state.

Le Play's great study of European working-class families tells the same tale.[15] He found that those families were coherent in which respect for parental authority and for the Decalogue persisted, and his whole work clearly shows that regular conduct was again the important factor, as it had been in the Romans two thousand years earlier—regular conduct arising largely from conditioned reflexes associated with routines and rituals of the family and of religion.

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[9] Robert A. Millikan, *Science and the New Civilization*, New York, 1930, pp. 68–69.

[10] 2nd ed., London, 1886, p. 1.

[11] Except possibly the notion that schools of thought command the future.

[12] "The Master said . . . 'It is by the Rules of Propriety [li] that the character is established.'" Confucius: *Analects*, Book VIII, Chapter VIII, § 2. Translation by James Legge.

[13] *Discourses on the First Decade of Titus Livius*, Book I, Chapter XI.

[14] *Histories*, VI, 56, 6–13.

Le Play's unsound families lacked a harmonious pattern of conditioned reflexes. With continuing industrial development the number of such families has probably increased, for about the end of last century Durkheim recognized and described a specific pathological state[16] which he called *anomic*. It seems to be due to an intensification and enlargement of the very conditions described by Le Play in his unsound families. Its differentia is extreme lack of cohesion. Durkheim speaks of an incoherent dust of individuals.

Still later Pareto, in his taxonomic studies of the residues, found the same thing.[17] The residues are widely current manifestations of sentiments, chiefly observable in nonlogical conduct. One class of residues, those of the so-called persistent aggregates, are plainly a product—in the main—of conditioned reflexes, rituals, and routines. In Pareto's considered opinion the persistent aggregates are the chief cohesive factor that binds societies together.

Here is a body of evidence and of carefully formed inductions. It points to a clear conclusion, to a conclusion that has been almost completely obscured by the European intellectual tradition. This conclusion has been obscured because the makers of the intellectual tradition, and still more its transmitters, like the political scientists of whom Aristotle speaks,[18] have rarely known human societies intimately at first hand. And when the facts have obtruded themselves, 'intellectuals' have too often regarded them as expressions of ignorant prejudice or superstition, unworthy of their notice, and as an impertinent intrusion of nonsense into their more serious concerns. The conclusion, greatly over-simplified, is this: The acquired characters of men are of two kinds. One kind is chiefly intellectual, the other arises chiefly from conditioning, and from rituals and routines. This it is that has been neglected by intellectuals; yet this is the older, the more primitive, and in many respects by far the more important of the two. Men share it, in modified form, with dogs and other animals.

A suitable dose, neither too much nor too little,[19] of such acquired characters, harmoniously interrelated, seems necessary to the stability of individuals and of societies, and as a foundation for orderly change. When social change is too rapid, a suitable dose is less often acquired. Without a very great deal of the resulting regular conduct, what we call liberty is impossible. Men will not *obey* custom, but if they feel a need to do right, that is if, like Morley, they are suitably adapted by conditioning to the ways of their own folk, they may often, at least in many circumstances, safely do as they please.

When societies are too unstable, individuals suffer. It seems probable that the psychoneuroses are most common in Durkheim's anomic people and that, for instance, disease of the coronary arteries, gastric ulcer and duodenal ulcer are most frequent in unstable societies. An index formed by adding appropriate measures of the incidence of these diseases and of divorce, and subtracting a measure of attendance at church, might sometimes run more or less parallel with an index of industrial development. Then would both—or neither—measure social progress? They would measure—what they measure.

CONCLUSION

It seems probable that, in a given place, at a given time, for a given end, there may be an optimum rate of change of a given thing. Some day this will be a subject ripe for careful study. Then the conditioned reflexes of men, as they are at any given time and in any given place, will be seldom negligible. More often than not, I suggest, when the end is survival, they will be again, as they have been so often in the forms that we name loyalty, the bonds of family, the sense of kinship, love of country, and religious devotion, powerful social forces, and dangerously lacking when in default. For note well that humanitarian sensibilities, liberal opinions, and social philosophies, in this respect like scientific attainments, are not the equivalent of the sentiments that accompany conditioned reflexes. In origin and in function they are different things. Sentiments of the first kind, arising more or less directly out of concrete experiences, hardly at all related to the intellect, closely related to what we call in some men breeding, in others discipline, in still others decency, act as cohesive forces. Sentiments of the second kind, much less a result of concrete experience and of conditioning, much more closely associated with intellectual activity, seem to have other functions, and not this one. Both kinds of sentiments will probably be powerful social forces in the future.

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[15] *Les Ouvriers Européens*, passim.

[16] *Le Suicide*, Paris, 1897, passim.

[17] *The Mind and Society*, New York, 1935, Vol. II.

[18] *Nicomachean Ethics*, Everyman's Edition, X, pp. 260–261: ". . . in all other cases those who impart the faculties and themselves exert them are identical (physicians and painters for instance) matters of Statesmanship the Sophists profess to teach, but not one of them practises it . . .

". . . they [the Sophists] have no knowledge at all of its nature and objects . . ."

[19] I suggest that there may have been too much, for various ends, about five centuries ago in China, and that there may be too little today in our own society.

The cohesive forces, though neglected and despised by 'intellectuals,' though weakened by rapid social change, might even save us from disaster. This we can only surmise, but that they will continue to operate is certain, "car il faut cultiver notre jardin," and they arise spontaneously, by conditioning, from this cultivation.

Meanwhile a meaningless word will still be meaningless. And yet we need not hate progress, unless, like Holmes, we do so in self-defense. That a meaningless word should have had for two centuries the fortunes of this word is no small thing.

A PAPER ON SOCIAL PROGRESS

By Crane Brinton

When I received the invitation to join in the discussion of this grand phrase, "social progress," my mind turned with the comforting assurance of professional habit to the history of the word "progress." The great Oxford English Dictionary confirmed what I already vaguely knew. The word is of learned Renaissance coinage from the Latin, and first appears in English at the end of the 15th century. It means a moving forward or onward in a purely physical sense; the Latin "pro" here carries no promise of better things ahead. Thus in 1590 Queen Elizabeth may make a progress through her kingdom; her kingdom makes no progress. Indeed, the Oxford dictionary cannot find a *clear* example of what it calls the "figurative" sense of the word—the sense of technical, moral, social "improvement" so familiar in our current vocabulary—until 1742.

I quite agree with Mr. Henderson that the word "progress" as currently used is meaningless. I agree also that the word is so overcharged with human hopes and fears that it can only with great difficulty be used as a symbol in performing logical operations. But almost every important word we try to use in performing such operations on problems in the social sciences is subject to similar, if less extreme, limitations. I should suppose that the use of the word "meaningless" had already aroused in this room sentiments not altogether suited to the most detached symbolic thinking. But even at the level of the confused and partisan thinking with which most of us human beings get along, "progress" seems today to be a word more charged with conflicting associations and sentiments than words like Truth or Justice. I think that I can best serve the purposes of this discussion if I try to disentangle some of the many meanings this meaningless word has borne since it soared from its humble Renaissance confines to its present handsome, wide, if somewhat unsubstantial quarters.

First, there is the sense of progress, improvement, in a process or technique. Thus in the technique of transportation we have all of us witnessed progress from the horse-and-buggy to the airplane. This is the sense of "material" progress which, contrasted with "moral" or "spiritual" progress or lack of progress is an apparently inexhaustible subject today for the teacher, preacher, and editor. Yet even in the comparatively limited sense of improvement in techniques, the word contains ambiguities. Such progress is commonly regarded as "scientific" progress, and rather snobbishly limited to the last few hundred years. Actually, however, our distant ancestors, even in the abysmal Dark Ages, made very important improvements in specific techniques without ever using the word "progress" or apparently having the sentiments now aroused by, or associated with, the word. The unknown early mediaeval inventor of the horse-collar, for instance, made possible a great increase in horsepower at a time when the science of physics can hardly be said to have existed. The mediaeval three-field system seems to have been a great improvement in land usage over previous systems. In fact, right up to the middle of the nineteenth century, invention—invention largely guided by empirical methods, by hunches and rule of thumb—seems to have gone on increasing without any clear relation to notions of progress prevalent after the early eighteenth century, and also without depending on what is commonly called "pure" science. Indeed, as Mr. Henderson likes to point out to his classes in the history of science, up to about 1850 applied science led the way for pure science; the steam-engine did more for science than science did for the steam-engine. Since that date it is true that these positions have been reversed, and that scientific progress—I mean the cumulative knowledge acquired in such fields as physics, for instance—has directly made possible improvements in techniques, or applied science. If in this Academy some hundreds of years from now, men still talk about progress, it may well be that this change in the roles of pure and applied science will seem the most significant thing in the history of the nineteenth century.

Second, there is the sense of the word progress which gets most of its prestige from theories of organic evolution developed in the last hundred years or so. I need hardly remind you that orthogenetic evolution has one set of meanings for the biologist and other and much vaguer sets of meanings for the ordinary educated man. As a form of progress, evolution is probably for most literate Americans associated with "Up from the Ape" or, since education does somehow contrive to spread a rather surprising amount of information, with a nice neat series of pictures starting with a little four-toed *Eohippus* scurrying over the Western plains a few million years ago, and ending with a Percheron and a race-horse side by side. Of the confusions which this notion of evolution has bred when it has been applied to problems of men in society I need hardly remind you. Poor Darwin has been brought in to justify some of the most amazing notions of a fine, beneficent struggle for life, from exterminating enemies in war to driving business competitors into bankruptcy. The once famous Benjamin Kidd was sure that Darwinism in politics meant no such crude competition as prevails among mere plants and animals; competition on a "higher plane" among human beings religiously devoted to "projected efficiency" (Kidd's own name for Progress as a goddess)—such competition alone could lift the race to the heights on which it belonged. I believe we have already rather liberally used the term "meaningless" tonight, or I would ask you to reflect longer on that term "higher."

Third, there is the sense of progress already emerging pretty clearly from what we have just considered, and that is moral or social progress. Here we encounter problems which the historian is bound to leave in a large part to the philosopher and theologian. It is evident that men do commonly distinguish—and not just in words but in action—between what they feel ought to be, and what is. This distinction involves a struggle to alter existing conditions "for the better," to use an old phrase of comparative innocence. Whether a given aim, particularly an aim so extensive as to be fitly called an ideal, is or is not ethically good is one of those questions with which I do not think the historian, as historian, can deal. He can try to make clear what men seem to have meant in the past when they talked of ethical good, and—a much more difficult task—how their talk and their action were related. I think we can say that for the last two centuries or so "progress" has been one of the important blanket-words under which men have sought to bring together what they felt to be ethically desirable. A good German Nazi would maintain that limiting women to domestic life in the monogamous family is a necessary part of progress, and a good many of our advanced thinkers hold that to emancipate them entirely from such a life is a necessary part of progress. In conventional logic they cannot both be right, but we are not dealing with the kind of human activities in which logic has much part. I think we shall have to say that they are both right, or if it makes you feel better, that they both *think* they are right. If Progress is a goddess, she must be right; the gods are always right.

Now as a goddess it is true that Progress is only a few centuries old, which makes her a mere child as compared with Justice. But I do not altogether share Mr. Henderson's low opinion of her charm and staying power, nor do I think she is quite fairly described as "a sterile intellectual construction." Perhaps I can make more clear what I am trying to say if I drop a metaphor which is already panting a bit from exhaustion anyway. The vague notions embodied in the concept of "moral progress" as held today by the ordinary West European and American seem to me to be linked to notions and feelings far older than the word progress, to notions and feelings about the future.

I do not disagree with the conventional outline of histories of the idea of progress. It seems true enough that for the Greeks—I start with them out of old habit, and because I do not think that earlier peoples like the Egyptians and Chaldaeans have much help for us in this matter—for the the Greeks the Golden Age lay in the past, and insofar as men thought at all about the general course of human history, they usually regarded it as a falling off from an earlier perfection. It is also true that Christianity, inheriting the old Eastern story of the Garden of Eden, and reinforcing it by very firm eschatological doctrines of Heaven and Hell, also made life on this earth something which could not in any general sense be greatly improved. Finally, it is true that as the Renaissance got well under way, men, and particularly intellectuals, began to think of history in a quite different way, to think of it as a process of development from barbaric inadequacies, physical and spiritual, to civilized adequacies, also physical and spiritual; and this line of development they projected into the future, putting their Golden Age on this earth indeed, but ahead, not behind, in time.

Though I am willing to admit that to the intellectual historian, this alteration in the location of the Golden Age, of Utopia, is interesting and important, I am more struck with the continuity afforded by the steady preoccupation of men with their future which is exhibited in all these notions of a better world. You may say that for the mediaeval Christian Heaven and Hell meant something very personal and, as the future goes, immediate; while for our contemporaries progress is impersonal and remote. That is, I grant you, a real difference; but in this paper I prefer to emphasize the fact that if the notion of progress is associated in men's minds with specific notions of "the good" which they feel strongly ought to be realized, then progress can seem very personal, very dear, very close. Modern revolutionists, most of whom are earnestly on the side of progress, seem to work as determinedly and as actively as if they expected the Second Coming instead of the fruition of a natural historical process. As long as the notion of progress is closely associated with our immediate notions of the difference between what is and what ought to be—and this seems to me to be the case in the Western World today—then progress will probably remain one of the more important ethical abstractions in common use.

In fact, it seems to me that some vague notion of progress has so far penetrated into the consciousness of most Europeans and Americans that even the onset of a very dark time of troubles foreseen by our prophets of doom might not destroy faith in progress. The Middle Ages witnessed invention, increase in wealth and population, much of what we call progress, without ever using the word, and indeed while subscribing almost unanimously to an official belief in the impossibility of any general improvement this side of the grave. There is usually some sort of gap between ethical beliefs and lives led under those beliefs. It would not appear unduly paradoxical to assert that even in the new Dark Ages which are ahead of us (according to the prophets, at any rate) when invention ceases and the sciences decay, men may still bear witness to their belief in progress. Such a belief does not seem to some temperaments to be very rich imaginatively, and it does seem to promise, without delivering, something tangible and concrete. But the leaders have been promising the Classless Society in Russia nearly a quarter of a century without apparently destroying popular faith in Marxist abstractions. I admit that in itself belief in progress does not seem to be a very consoling belief; but it may well be a bit short-sighted of us to assume that all that men are likely to need from such vague and semi-religious beliefs is consolation. Progress is probably a fair-weather goddess but need we anticipate a future of hurricanes?

I am afraid that some of you have by now decided that I am a rather lukewarm, and even treacherous, advocate of progress. Some of you perhaps feel that I ought to face the question, well, after all, aren't we as a race getting ahead? Isn't there evidence of progress even in concrete morals, if not since the Greeks at least since the cave men? These are endless questions, and certainly cannot be answered scientifically. But they are too natural to be unfair, and in these last few minutes of my paper I should like to suggest, not an answer to them, but one reason why they seem to us in 1939 so pressing.

Briefly, we are living today in the backwash of one of the most extraordinary waves of optimism that has ever struck mankind. Into the historical background of the kind of belief represented by men like Herbert Spencer, H. G. Wells, Herbert Croly, and hundreds of other scientists and men of letters of their time I cannot go here. Put very simply, they were so impressed with concrete evidences of progress in technique, with the grand course of human development they thought Darwin taught them, with the freedom and readiness they themselves enjoyed in thinking about human behavior, that they came to take their words for all men's deeds, or at least prospective deeds. It is unwise to take your own words for your own deeds. It is disastrous to take them for other men's deeds. Herbert Spencer noted as a sign of progress in his own day the fact that women were abandoning the use of rouge and face-powder, a process which he firmly believed would continue as women grew more and more away from the vestiges of savage adornment.

This last is a trivial and undignified matter, but it illustrates the kind of thing our distinguished predecessors passed over in their hurry and hope. In some ways it seems that change in the behavior of men in respects socially very important is almost as slow as the kind of change the geologist studies. In other respects, notably in certain fashions of dress, and in many of the kinds of writing literary people do, in talk and so on, the behavior of men may change fairly rapidly. It was the fashion among French aristocrats about 1789 to talk irreverently and as wittily as possible against the Church; it was the fashion among these same aristocrats ten years later to display a sorrowful reverence when they talked of the Church. The total amount of lying, thieving, gambling, overdrinking and overeating, wife-beating, cheating at cards, bullying and boasting, and similar acts unsuitable in the good life I feel almost sure hardly varied among French aristocrats in those ten years.

Now if I may waive questions about the relativity of moral ideas, I can admit that there has been a rough agreement among many men in our Western world for some thousands of years as to important features of the good life. If we could have less lying, less cruelty, less jealousy, less vanity, less rudeness on this earth I think we might well agree that there had been something tangible in the direction of what most of us vaguely mean by the subject of tonight's symposium. This would certainly be a definite kind of social progress. Unfortunately we know but little as to how men's behavior in such respects changes; and what little we know suggests that it changes very very slowly, much more slowly than forms of government, social planning, and even religion.

One final word. I regard the general tone of my paper as optimistic. Only as measured against the inordinate and almost unprecedented hopes for social progress held by many educated men of the years just before 1914 do the events of recent years seem unduly horrible and unbearable. The pessimism and the doubt so evident among us is in some part but the natural revulsion from hopes strung too high and therefore deceived. I suggest that in the long run of history we have no right to expect rapid changes in those fundamental, if undignified, forms of human behavior which largely condition social life. Men never can catch up with their prophets; but this I think is as true when the prophet is called Hitler as when he is called Wilson.

SOCIAL PROGRESS

By Edwin Bidwell Wilson

Mr. President, had I not stood for some time in your position as President of this Academy and come thereby to understand the serious responsibilities of the office in respect to our meetings and had I not been put greatly under obligation by the readiness with which the Fellows of the Academy supported me, I should surely have declined your insistent invitation that I appear in this symposium on What Constitutes Social Progress, for knowing myself to be incompetent in these premises I prefer to be a listener rather than a speaker upon them.

Mr. Henderson has shown that the term social progress is meaningless in the scientific sense and Mr. Brinton, after quite agreeing, has come to the general conclusion that social progress denotes an aspiration.

It was instructive to me to learn that the lexicography of the word progress shows that the modern meaning first appeared 75 years after Bunyan's Pilgrim's Progress which banished my earlier interpretation of 50 years ago that progress in this connection had the Victorian connotation. I am also interested to learn that a recent picture in the papers of Smith College girls in the Harvard tank surrounded by little but water, however much it may mean for technological progress in the portrayal of news, does not necessarily mean any real social progress over the Victorian period but only a change in some of women's styles.

Coming after the previous speakers it would be folly for me to try to tell you what social progress is or may be; rather will I turn to the questions: Why can we not attribute a scientific meaning to the phrase, and is there any hope that we may ever be able to do so?

First let us look at science and engineering: In what does their progress consist? Certainly it consists of something more than just journeying around like Queen Elizabeth. We have more information, we can do more things with greater assurance of success than we could 2000 years or 200 years or even 20 years ago. With all the wastage in scientific and technological effort there is an accumulation of knowledge and of method with a resultant increase of control in some fields of activity. This is true whether of physics or of biology or of medicine. The scientist gives definitions based on increasing discrimination with respect to facts. The scientist builds upon previous knowledge. He may make no spectacular discoveries; his may be only the patient classification seen in our research herbaria. Indeed scientists are proverbially suspicious of brilliancies. I would not give the impression that every well established result leads at once to an improvement in technology or in our control over nature; nor would I assert that improvements in these matters do not still sometimes come from invention, which in some respects is ahead of that coordinated body of knowledge we call science. What I desire to emphasize is that throughout all these fields, pure or applied, there is advance of the sort one finds in the growth of a coral reef—there is building upon what is already laid down.

Such is also true to no inconsiderable extent in some fields called humanistic. Our knowledge of historic fact has increased through research—again with all allowances for certain wastages. The same is true of linguistics or philology. Is this true, too, of the social sciences?

Let me begin by quoting from a translation from the Gest Chinese Research Library at McGill University:[1]

> "In the year 524 B.C., Emperor Ching of the Chou dynasty thought that the coins in circulation were much too light, and issued an order to mint heavier coins and banish the light ones from circulation . .
>
> "Regarding the drastic change, Shan Mu-kung, a minister of the government, comments as follows: From time immemorial the monetary system of the government has been so regulated as to relieve the people in time of distress (i. e., economic depression). When the inconvenience of the people is not great, more heavy coins are put into circulation for the reason that when the coins are light prices of commodities go up. In this case the heavy coins are standard value, while the light ones are auxiliaries—but they are both in circulation. On the other hand, if the inconvenience of the people is great they cannot bear the burden of heavy money. The light money automatically becomes the standard value and the heavy auxiliary.
>
> "Now, the Emperor has ordered the abolition of light coins completely. The immediate result of this change will be an enormous decrease in the income

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[1] See Wên hsüan t'ung k'ao (Edition 1896, A.D.), Chap. 8, pp. 4–15, by Ma Tuan-lin, 13th century A.D. Rendered by S. D. Quong.

> of the people and consequent hoarding will be inevitable. All this causes a bad effect on the national treasury and directly raises the rate of taxation. When the rate of taxation is raised, financial disaster and political discontent follow.
>
> "Preparation should be made in advance to meet the coming of a financial crisis. If remedy is to be applied only after the crisis has arrived it may be impossible to meet the exact condition and consequently will cause great anxiety."

This is from a compilation made in the 13th Century, A.D., and based upon original Chinese sources. I do not know who the minister Shan Mu-kung was or whether he actually lived in 524 B.C. as implied. Having regard to the changes in meaning of words, as exemplified by "progress" itself, and to the difficulty compilers and translators have to avoid reading into ancient texts meanings it is unlikely the ancient writers could have intended, I still submit that the quotation is a remarkable statement—as remarkable if it were made today as if it were made whether in the 13th century A.D. or in the 6th century B.C. It is a statement of Gresham's law as good, I think, as one could find anywhere and indeed it seems to involve refinements rarely incorporated in the statement of that law. I have read and heard much looser talk about money and economic control in very recent years.

Now I do not raise the question: Was Shan Mu-kung right? To be right in any complex field implies a statistical inference based upon a careful collection and a discriminating comparison of a large number of varied instances. To be right in geometry means merely that we reason correctly from stated consistent premises; we have long since determined one or more sets of such premises. But merely to reason correctly from stated premises in a complex field is almost the surest way to ensure that we are wrong—for in the first place we do not know that the premises are consistent and we are tolerably certain that owing to the very complexity of the field there may be such an oversight on our part of the variables which should have been covered by our premises as to make those premises even if consistent quite too fragile a foundation for verifiable truth.[2]

Shan Mu-kung was probably a practioner, a practical man, rather than a theorist.[3] Persons who deal thoughtfully with affairs may, like the technologist, come to sound truths well in advance of truly scientific analysis—these are discoveries. Indeed it is, I believe, a sound generalization from long experience that until such practical persons have come upon sound truths no science can develop and that the development of science comes from the painstaking examination of those truths to ascertain what is a better, a more precise, statement of the conditions under which the truth is valid and of those conditions under which it would become invalid. When science has become highly developed—has made progress if you will—it may lead, it may even become too proud to follow or so proud as to assume that its wisdom may be stretched to cover all matters under Heaven howsoever widely removed from the special competency of the scientist or his science—but pride often leads to a fall. I have tried to point out that when science is not well developed any pride of this sort whether of the scientist or of his subject is almost certain to lead to a fall. Aristotle in closing his Ethics seems to fear that the academicians who discuss political science are fallible if not fallen—and one may wonder whether his observation was any more true of the Sophists than it may be of their present followers. I think he would bet on Shan Mu-kung or on Josiah Stamp or possibly even on Hjalmar Schacht as against Irving Fisher or J. M. Keynes.

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[2] See, for example, Alfred Marshall, Principles of Economics, 8th Ed., 1930, Appendices C and D. "Economics contains no long chains of deductive reasoning," p. 781. "Even in mechanics long chains of deductive reasoning are directly applicable only to occurrences in the laboratory. By themselves they are seldom a sufficient guide for dealing with the heterogeneous materials and the complex and uncertain combination of the forces of the real world," p. 771. "It is obvious that there is no room in economics for long trains of deductive reasoning: no economist, not even Ricardo, attempted them. It may indeed appear at first sight that the contrary is suggested by the frequent use of the mathematical formulae in economic studies. But on investigation it will be found that this suggestion is illusory, . . .", p. 781. One should read the whole text of these Appendices. I may say that entirely apart from any difficulties in economics which may inhere in trusting mathematics, it not infrequently happens that the mathematics itself of the mathematical economist is far from completely trustworthy.

[3] There is no absolute dichotomy between fact and theory or between practical and scientific pursuits; rather is there involved a difference in the weighing or in the neglect of the "other things" which the theorist or pure scientist postulates "to be equal," but which in practice so seldom are. A distinction is beautifully drawn by H. Pirenne in the preface to the English translation of his Economic and Social History of Medieval Europe (p. xi): "There are still so many gaps in our knowledge that I have in many cases been obliged to resort to probability or to conjecture, in order to explain events or to trace their interconnection. But I have been careful not to resort to theories, lest I should do violence to the facts." Those who appreciate this distinction will not make the error of thinking of science as chiefly theory instead of as chiefly coherent factual knowledge; the few successful general theories are so impressive in their isolation that they tend to blind us in the matter of what science is—also speculation is so attractive and a multiform array of detail so tedious! The "expanding universe" may be the bauble of a decade; positional astronomy is a creation of centuries.

When referring to this matter of pride in science and of that overweening pride of the scientist which leads him to pontificate about all sorts of topics on which neither he nor his science are competent we need not think of the social scientist as the worst offender today. He does not talk carelessly of physics or chemistry or astronomy, and except as he abandons the study or misuses the classroom to become a frank propagandist for some social program, he is usually careful in his utterances, suffering from an inferiority complex born of what he knows to be the incompleteness and unsatisfactoriness of his knowledge rather than from a know-it-all blatancy. It seems to be the natural scientist, particularly in the so-called physical sciences, who errs most in stepping out of his role with pronouncements upon economics, religion or what-you-will, based not upon careful study of those fields but upon his own desire to preach. An eminent pathologist who turned to psychology, Sigmund Freud, gained a deserved reputation for his analysis of such phenomena. However serious the sexual libido or how variable its manifestations, I sometimes wonder whether there be not even more seriousness in the lust for harangue. Who knows but some future scientist may acquire great repute from an analysis of the all pervasive and overwhelming effects upon us of tittilations arising not from the spermatic but from the vocal cords!

I fail to see how we shall ever be able to impute scientific meaning to such a term as social progress until social science has advanced as a science considerably further than seems as yet to be the case. And I fail to see how social studies can become scientific as long as the *mores* of our social scientists place brilliancy so far ahead of patience and generalities so far ahead of specification. We very much need a handbook of the social sciences which tells us what is true under what restrictive conditions. In its first edition it might be a very small book but it would furnish a very different base for growth from that afforded by the 15 volumes of the Encyclopedia of the Social Sciences,—growth in grace rather than in stature.

You may be interested in the experience of the Social Science Research Council in attempting to find out what is known in social science. Shortly after appointment as Executive Director of that Council Professor R. T. Crane pointed out that social scientists seemed usually to start research on some large ill-defined subject practically *ab initio* so that it was impossible to see just from what their conclusions flowed or even where they fitted into what was known. He determined to set about making social science grow from bed rock or as nearly from bed rock as one could arrange.[4] A committee of three persons each with a considerable record of publication in the field of social psychology was selected. This committee was asked to choose some topic, no matter how small, with which all three were professionally familiar and to put down: First, that knowledge on their selected topic which they all agreed had been ascertained and corroborated by critical observation; second, some propositions which had been suggested by investigators on the basis of a certain amount of observation and which could probably become incorporated with this body of ascertained knowledge provided they could be corroborated; and third, some proposals for further research which if successfully prosecuted would probably develop new knowledge coherent with the foregoing. This was an excellent program: It left the choice of a special field to three experts. It was just a little start toward a series of short monographs which should foster research, not spectacular but coherent, in which all who wished might collaborate toward an organic growth of certain small nuclei in the social science field.

The results of this and similar tentatives have not been notable. It immediately appeared that the three psychologists could not agree on anything, in any no matter how restricted a subfield of their studies, which could be considered as known. Next they wanted to hold and were permitted to hold a conference of twenty or thirty other experts to tell them what was known —this was foredoomed to failure, one does not go to Babel to compose a pocket dictionary. Then they were permitted to engage a considerable number of sub-experts to canvass the literature of the subject and these able enterprising young people brought in such reams and reams of stuff that the committee of three were sunk—or should I say were tossed about in bewilderment upon the froth? Finally the committee as a committee gave it up. One member prepared a monograph to which I believe the others would not entirely assent and which was not of the sort originally contemplated. I do not say that the monograph is useless, it may be better than many, but the experiment to get a baby handbook on a little field failed. Although other similar experiments in other fields have usually been abortive, we still have some hope that sooner or later we may take a few steps toward establishing foundations upon which some topics in social science may grow coherently.

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[4] I wish to absolve the Executive Director from all liability for my statements. I have been upon the Committee on Problems and Policy of the Social Science Research Council continuously for a decade and assume full responsibility not only for my statements but for the possible indiscretion of my making them in this place.

Until such coherent growth has begun and gained considerable momentum, until social science has advanced somewhat further from the zoology of the Bestiaries toward that of the Agassiz Museum, we shall probably not have the background on which to say what is social progress, and when social science has thus advanced we shall not be talking in terms of social progress but rather in those of various sorts of social progress and of social retrogression, as indeed a discriminating historian like Mr. Brinton or an analytical scientist like Mr. Henderson already do.

Mr. Brinton feared you might think him pessimistic. I fear you may think I have attacked social science. Not so. One does not attack the sea slimes from which we all derive. One notes merely that they do not cohere and build up like the coral reef. Science is what coheres and builds up. It is the residue of dead scientists who have left something after their hopes and emotions and life are gone. If somehow we can get a little more calcium into the system of the social scientist he too will make his deposit and perchance will not have had any less satisfactory life.

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